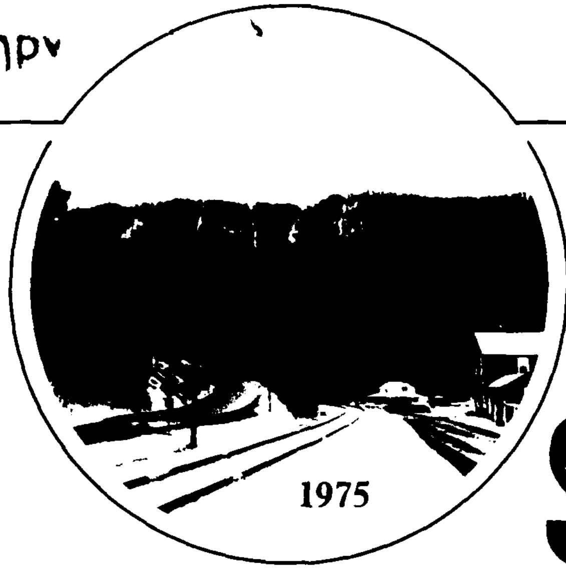
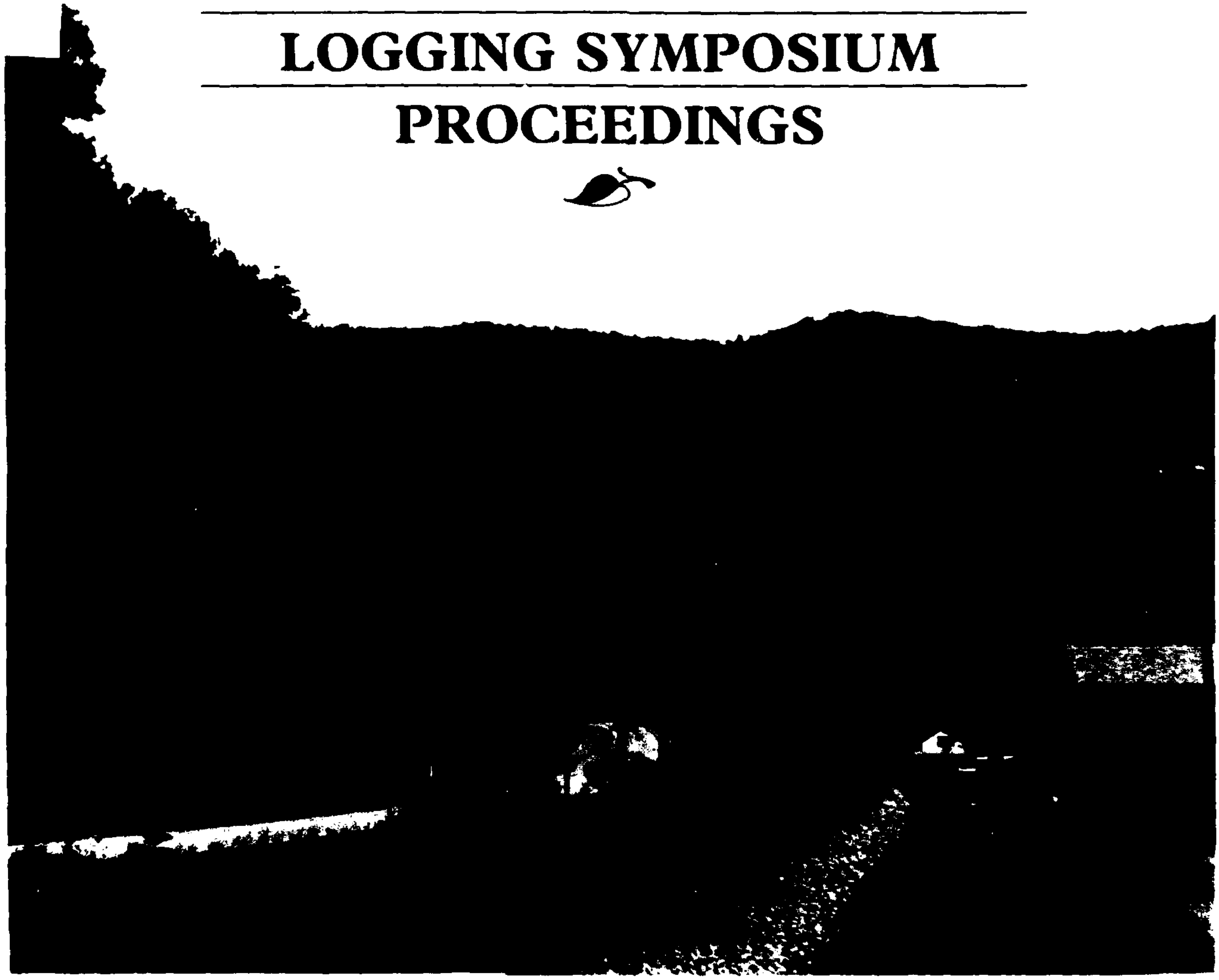


MOUNTAIN LOGGING SYMPOSIUM PROCEEDINGS



June 5-7, 1984
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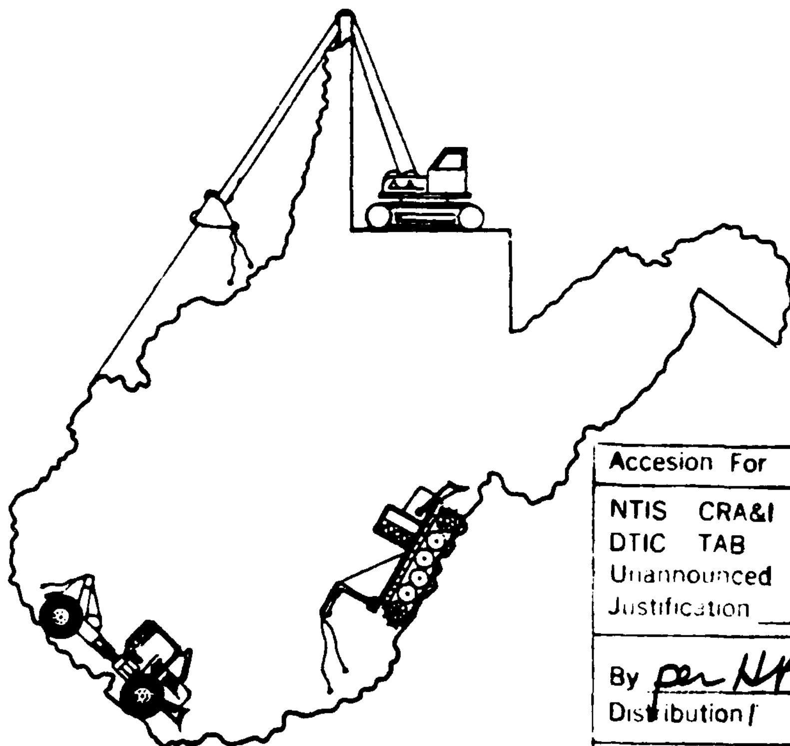

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TABLE OF CONTENTS

STEEP TERRAIN LOGGING IN NORWAY

Professor Dr. Ivar Samset[1]

ABSTRACT

The organizers of this conference have asked me to put the main emphasis on Norwegian research and development in mountain logging. Our research programme started in 1949 and has continued for 35 years. This paper will be a survey of only some of the results.

Norway is the mountainous part of the Scandinavian countries. According to our national survey where terrain classification has been carried out since 1954, approximately 25% of the productive forest land is located under steep and difficult terrain conditions.

INTRODUCTION

The invention of the wheel took place 4 - 5000 years ago. The line technique is older than the wheel and is the oldest method of transport on land for mankind. Ropes from fibres or strips of skin were used in the ancient civilized nations of East Asia.

The development of cable systems took place in the following areas and periods:

1. The Oriental civilization.
2. Late middle-age 1300 - 1600 (Japan and Europe).
3. New industrial age 1550 - 1930 (Europe, Japan and America).
4. Present time 1930 - (all countries with difficult terrain).

In Europe the cable systems were used to take down timber from steep mountains. Gravity cable systems have been used since 1852 (gravity cable, pendulum cable ways etc.). In Norway cable transport was introduced in 1865.

The New World, America, was populated by emigrants from Europe. Some of the best people found new homes and new challanges in a continent with many possibilities. This was also the case with the development of winch and cable systems. The first developments took place in the eastern part of the continent. A rather complicated cable crane was in use in the US Southern States as early as

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1/ Director of the Section of Forest Operations and Techniques at the Norwegian Forest Research Institute, Head of the Institute of Forest Operations and Techniques at the Agriculture College of Norway, Past-President of the International Union of Forestry Research Organizations.

in 1892. On the American West-Coast the problem was to pull very heavy logs. The first Donkey-yarder was built in 1855. Many people took part in a wide range of developments. This gave feed-back to Europe where the development of modern cable cranes started after the last world war.

The easy communication between countries and continents have initiated a faster development of cable systems than ever, and trough meetings, consultations and symposia ideas have been exchanged.

Under some conditions, cable crane operations may be replaced by other methods, such as airship-, balloon- and helicopter transport or by tractor operations if terrain conditions are not too difficult.

Terrain classification has helped in planning the communication network as well as the operational activities. It is better understood today that the choice of operational methods depends on the road-network and its location in the terrain configuration.

Table. 1. Work place time for rigging up and rigging down in manhours and in number of days for the crew, for various types of Norwegian cable systems investigated during the period 1951 - 1980.

Type of cable system	*Number of installations*	*Average*		*Man hours*			*Number of crew*	*Days of installation and dismantling*	
		L_1, m	*Supports*	*Instal- lation*	*Dismant- ling*	*Total*		*Used Wo* 1)	*Wo = 6 hrs./day*
Twin-cable, Stengestad - Blesa (1953)	1	1 100	7.0	821	-	-	4.1	26.6 (7.5)	33.3 (2
Stationary pendulum cableway, Kviteseid (1951)	1	1 200	2.0	270	-	-	3.0	12.0 (7.5)	15.0 (2
Movable pendulum cableway (1951-53)	4	448	1.5	48.2	8.1	56.3	3.0	2.5 (7.5)	3.1
Cablecrane with top-mounted winch (1955-59)	5	354	1.4	57.7	16.5	74.2	3.0	3.5 (7.0)	4.3
Cablecrane with valley-mounted winch (1955-58)	8	581	1.1	72.2	11.8	84.5	3.0	4.0 (7.0)	4.7
Radio controlled cablecrane (1967-80)	25	480	1.0	-	-	52.1	3.0	2.9 (6.0)	2.9
Moxy running skyline (1978-80)	2	398	0	13.8	6.0	19.8	5.0	0.66 (6.0)	0.66
" " *Side movement*	17	449	0	2.9	-	-	-	-	(0.10)
Igland prototype running skyline (1978-79)	3	127	0	3.0	0.8	3.8	2.0	0.32 (6.0)	0.32
" " *Side movement*	16	138	0	1.2	-	-	-	-	(0.10)
Vossa winch. Cablecrane yarding (1953-59) Summer	21	155	1.4	9.3	3.7	13.0	3.0	0.62 (7.0)	0.72
" " *Winter (1957-58)*	4	304	2.0	18.9	9.3	28.2	3.0	1.34 (7.0)	1.57
Yarding with running skyline (1978-80)	3	107	0	3.3	0.8	4.1	2.0	0.34 (6.0)	0.34
" " *Side movement*	11	91	0	1.2	-	-	-	-	(0.10)

1) *The normally used work place time (Wo) in bracket*

2) *Installation only*

LONG DISTANCE CABLE WAYS AND CABLE CRANES.

The cable systems may be classified as follows:

Long distance cable cranes :	>700 meters
Medium distance cable cranes:	300 - 700 meters
Short distance cable cranes:	100 - 300 meters

The old cable ways transported timber from a centrally located pile on a cable plateau to a landing in the valley. Such systems are not any longer in use. They are replaced by access roads to the plateaus.

The long distance cable cranes were usually 800 - 1200 meters and some were 1500 meters. The crane collects timber from steep hillsides and transports it downhill to a landing. Some systems used a single drum winch located near the top of the cable crane. In other systems the winch was placed near the landing in the valley. Long distance cable cranes are not in use any longer due to heavy strain on the workers and long installation time (table 1).

MEDIUM DISTANCE CABLE CRANES.

These are normally working on distances between 300 and 500 meters but the distance may be extended to 700 meters in difficult cases. The daily production from cable cranes decreases considerably if the distances are longer than 450 meters due to the heavy work for the terrain crew.

The work in steep terrain is harder than on flat ground. According to our ergonomic studies the workers adjust their tempo in relation to terrain difficulties. The workers performance when felling and choker-setting in 70% slopes are 1/3 of the performance when working on flat and even ground. Therefore, the terrain work is reduced to felling and choker-setting only. Limbing and bucking is being carried out by a harvesting machine at the landing. In most cases the workers combine felling and choker-setting in one transport sequence.

The road network is planned in such a way that cable supports are avoided.

NESTESTOG RADIO-CONTROLLED CABLE CRANE.

The Norwegian radio-controlled cable crane is a fixed skyline system which operates on distances up to 1 000 meters. It is normally used on distances less than 500 meters. The carriage is pulled along the skyline by means of an endless mainline. (fig. 1).

Skyline	D = 20 mm	6x19+1
Mainline	D = 12 mm	6x26+1
Rigging up line I	D = 1.5 mm	6x19+1
Rigging up line II	D = 3.3 mm	6x19+1

The truck-mounted yarder has a grooved wheel pulley for the mainline, spools for the rigging up lines and single drum winch with 100 meters straw line (D=10 mm 6x19+1) which is used for tightening the skyline and for other rigging up or down purposes.

Figure 1. The Nestestog radio-controlled truck mounted cable crane and radio-controlled carriage.

The endless mainline may be shortened or lengthened according to the length of the cable crane by inserting or taking out a 50 meter length. For this purpose fast couplings are used. The endless line may be tightened by moving the yarder away from the spar tree on the landing or on the truck road.

A hydraulically driven grooved wheel pulley moves the endless line and the carriage forward or backward. All the other drums on the yarder are also driven by hydraulic motors.

There is no operator on the yarder. The yarder is remote controlled and each of the workers in the crew has a transmitter. The transmitter sends a signal (a tone on the radio wave) which is picked up by the receiver and via a relay unit and magnetic valve controls the winch. A timer is also built into the receiver which can maintain a signal for as long as desired. If the timer is adjusted for 600 meters one must first press the button for "start - timer" and then the button for "pull" or "haul-back". If the transport must be stopped, this can be done by pressing the opposite "stop" button.

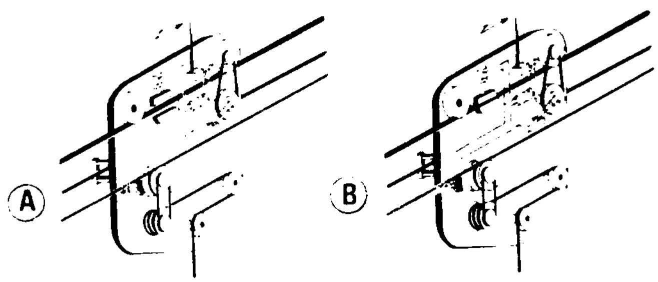


Figure 2. Nestestog radio-controlled carriage.

The carriage is also radio controlled (fig. 2). The electrically operated parts within the carriage are powered by a battery in the carriage. An alternator charges the battery. The battery drives an electric motor with a hydraulic pump. This gives hydraulic pressure to hydraulic cylinders which may close a grip on the skyline and a brake on the capstan drive for the hoist drum.

When the carriage is being pulled by the main line along the skyline the grip is open and the brake on the hoist drum is locked. When one of the workers wishes to stop the carriage he sends a signal from his transmitter to the receiver in the carriage. This starts the electrical motor and the hydraulic pump. The grip fastens on the skyline and the brake on the hoist drum is released. By moving the endless mainline the capstan and the hoist drum start to rotate, pulling the hoistline in or out.

As soon as a load has been lifted up to the carriage a new signal from the transmitter to the receiver in the carriage starts the electric motor and the hydraulic pump in the opposite direction. The grip on the skyline opens while the brake on the capstan closes. Next time the main line moves it pulls the carriage in one direction or the other.

The remote control and the timer are a great advantage. It is the person who needs the forces who controls the yarder. The remote control is also of great help when rigging up the cable crane.

Figure 3. Nestestog radio-controlled cable crane with the Logma delimber at landing, Kviteseid, Telemark, 1979.

Normally there are 3 workers in the crew:

2 terrain workers, who fell the trees and set the chokers.
1 worker at the landing operates the limbing machine and unhooks the chokers.

All three workers have a transmitter, and can control the yarder, the timer or the carriage.

First the carriage stops at the worker high up in the hillside. He has felled a bunch of trees and set the chokers. By means of his transmitter, he pulls in the hoistline until the load reaches the carriage. He then starts the timer and the loaded carriage moves downhill, zero-man operated. The terrain worker can continue to fell a bunch of trees with his chainsaw for a new load.

The carriage stops automatically (controlled by the timer) near the landing. When the operator on the limbing machine has finished the limbing and bunching of the previous load, he uses his transmitter to take down the new load. He returns the empty carriage to the other terrain worker (zero-man operated by the timer). He can use the time between two loads to limb and bunch the trees in the load he has taken down on the landing (fig. 1).

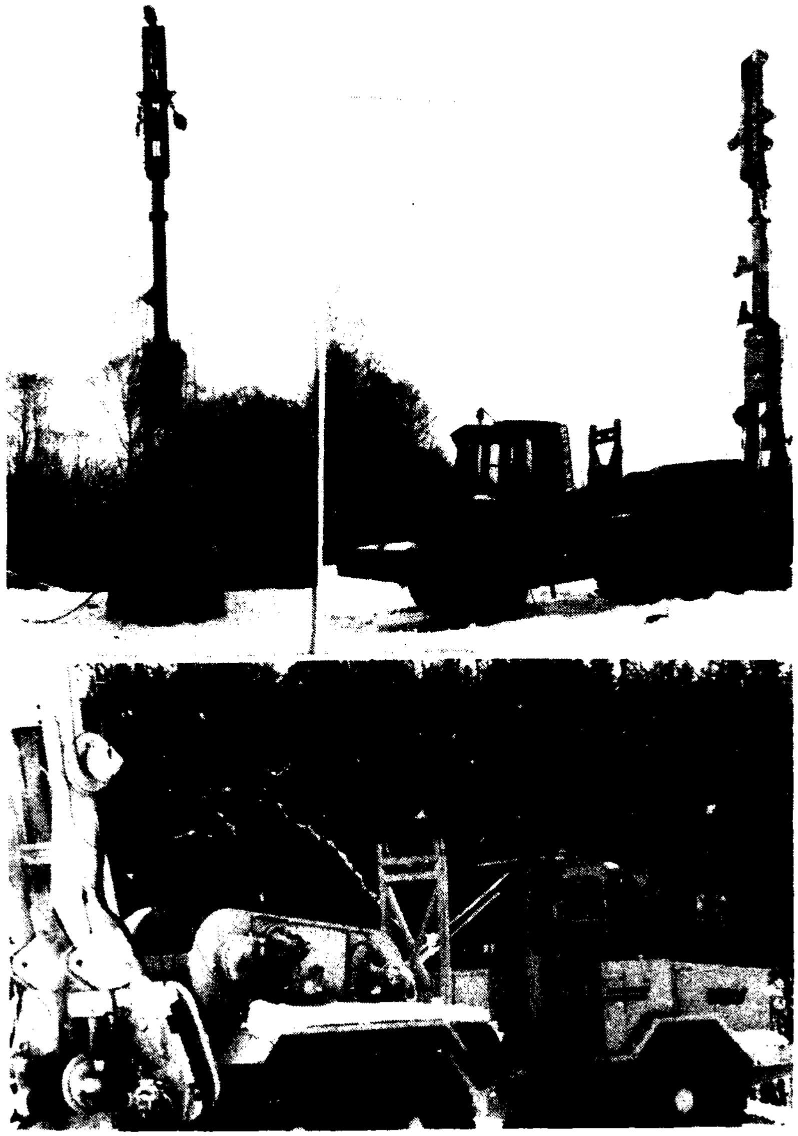


Figure 4. The Moxy yarder with Lantec 3-drum interlock winch.

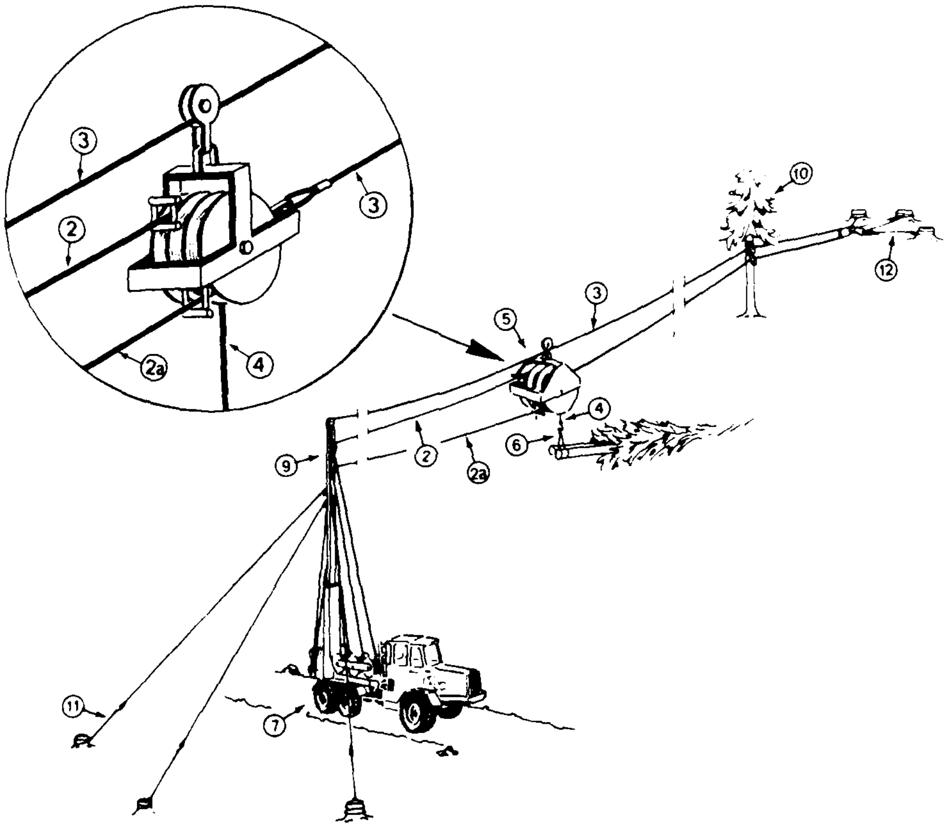
MOXY CABLE CRANE WITH RUNNING SKYLINE.

The yarder is constructed by the Moxy company in Norway in cooperation with the Norwegian Forest Research Institute. It has a 3-drum interlock winch, built by Lantec Industries Ltd. in Langley B.C. The total weight of the yarder is 280 kN and the tip-/telescope tower is 15 meters. The yarder is powered by the forwarder's diesel engine with a power of 154 kW (fig. 4).

The maximum speed on the main- and haul-back lines are 11 meters per second and the maximum main line pull varies from 21 to 33 kN (full and empty drum). The main line, haul-back line and slack pulling lines have the same dimensions D=14 mm (6x26+1). The maximum logging distance is 700 meters but normally the cable crane operates on distances between 300 and 500 meters.

Mainline	L = 700 m	D = 19 mm
Slackpulling line	L = 700 m	D = 19 mm
Hoistline	L = 50 m	D = 19 mm
Haul-back line	L =1400 m	D = 19 mm
4 guylines	L = 70 m	D = 18 mm
Strawline	L =1100 m	D = 8 mm
2 rig up lines	L = 760 m	D = 2,1 mm
1 rig up line	L =1400 m	D = 4 mm

Besides the main-, slackpulling and haul-back drums, there are hydraulically driven winchdrums for all the other lines and they are located near the foot of the tower.



2 Main line to the upper side of the carriage drum 2a Slackpulling line to the lower side of the carriage drum
3 Haul-back line (running skyline) 4 Hoist line (from the middle drum part) 5 Carriage
6 Tagline with chokers 7 Three-drum interlock winch 9 Tilt telescope tower 10 Tail spar
11 Chokers fixed to stumps in order to anchor the guylines from steel spar 12 Tail hold

Figure 5. The Moxy cable crane with running skyline and drum carriage.

The three winch drums are interlocked. The drum speeds are continuously varied by means of planetary drives inside each drum. The motor M1 powers the three drums. The hydraulic motor M2 adjusts the speed of the haul-back drum in relation to the main- and slack pulling drums. The hydraulic motor M3 adjusts the speed of the main drum and of the slack pulling drum in relation to each other.

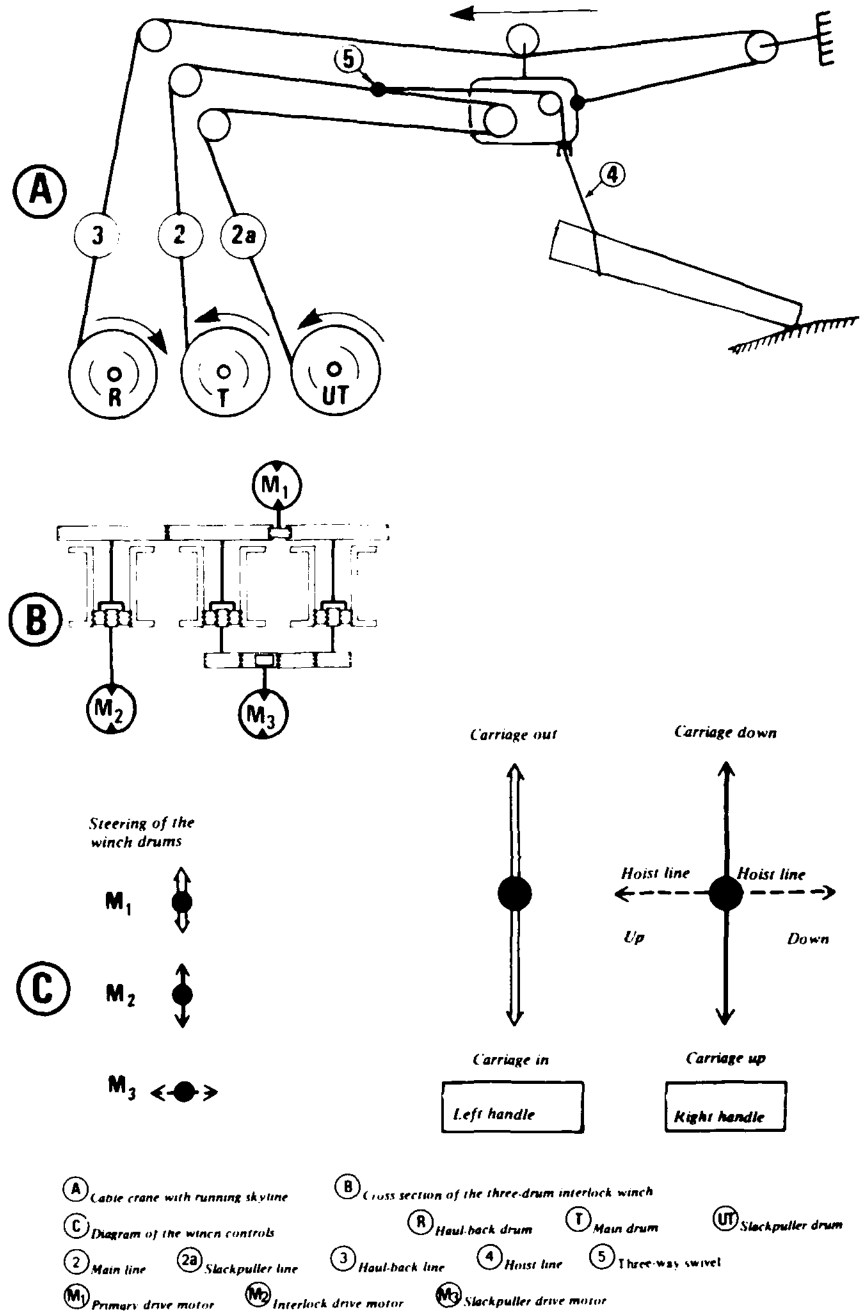


Figure 6. Cable crane with running skyline and triple-drum interlock winch.

The motor M1 powers the three shafts which rotate the planet carriers in the planetary drive. The motors M2 and M3 are connected to the sun gear in the planetary drive. As long as the three sun gears stand still, the three winch drums rotate at the same speed. If one of the sun gears starts to rotate in one or the other direction powered by M2 or M3 its winch drum rotates slower or faster than the other drums (see fig. 7). In fig. 6, A shows the running skyline system, B shows the three interlocked drums and C shows the operation of the winch controls.

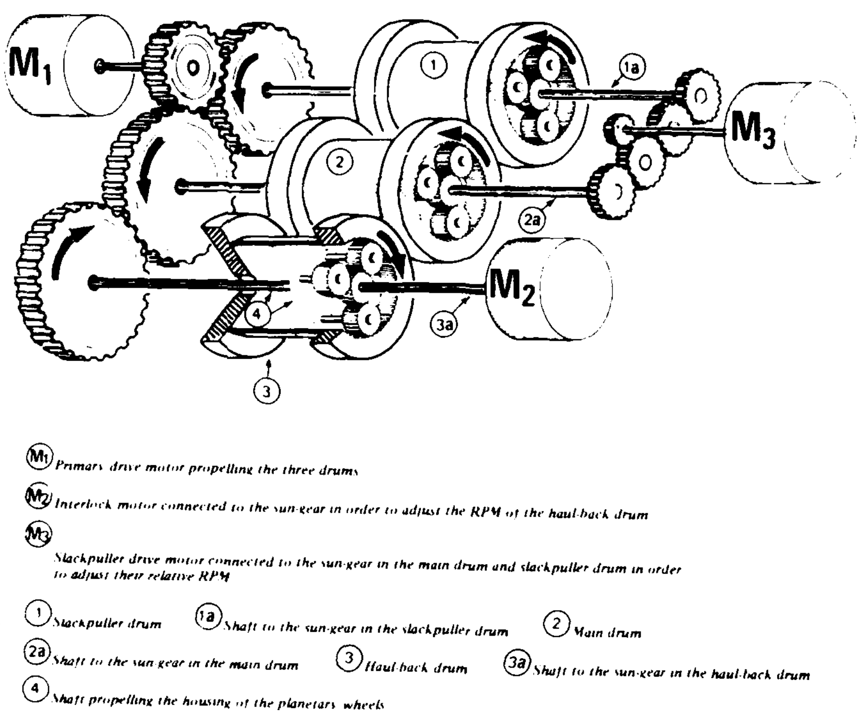


Figure. 7. The triple-drum interlock Lantec winch used in the Moxy cable crane.

An interlocked winch has high internal torques. It is necessary to dimension the winch and its gearing accordingly. The power flow in the Moxy yarder was investigated in our laboratory (table 2). P1 is the total power in the system. P2 is the internal power between the main- and haul-back drums. The braking power in the haul-back drum is regenerated into the main drum. P_T is the resulting power which moves the carriage and the load along the skyline.

The cable crew consists of a foreman, a winch operator, two choker setters, a chaser man at the landing and an operator on the delimbing machine.

The foreman leads the daily work, and prepares for the next line-change. He prepares the anchoring for the guylines and pre-sets the anchoring straps as well as the tail hold.

The cable yarding takes place along a 20 meter wide corridor on one side of the skyline. One choker setter works high up on the hillside and the other lower down on the hillside. They are both felling and setting the chokers. The winch operator alternates between the two choker setters and brings in the first load from one of the terrain crew and the second load from the other. When the 20 meter corridor has been logged the foreman already has prepared for the line change. He moves the tail block from the first corridor to the next by means of the straw line. The yarder is moved along the truck road to the next corridor. The line-change takes ordinary half an hour. Afterwards the felling and the yarding of full trees from the next 20 meter corridor can start.

Table 2. The power consumption in kW for the Moxy yarder, yarding unbranched Norway spruce on Myrtillus type of forest floor (6 meters per second).

Pil-høyde *Rope sag* f_m %	Helling *Slope* $tg\alpha$ %	Transport oppover *Uphill transport* Hengende last *Hanging load* P_1 (kW)	P_2 (kW)	P_1 (kW)	Halvslepende last *Highlead skidding* P_1 (kW)	P_2 (kW)	P_1 (kW)
8	0	175	171	4	156	129	27
	25	216	191	25	192	145	47
	50	262	219	43	230	168	62
	75	310	255	55	268	195	73
16	0	101	97	4	101	74	27
	25	137	112	25	134	87	47
	50	173	130	43	164	102	62
	75	207	152	55	191	118	73
Pil-høyde *Rope sag* f_m %	**Helling *Slope* $tg\alpha$ %**	**Transport nedover *Downhill transport* Hengende last *Hanging load* P_1 (kW)**	**P_2 (kW)**	**P_1 (kW)**	**Halvslepende last *Highlead skidding* P_1 (kW)**	**P_2 (kW)**	**P_1 (kW)**
8	0	175	171	4	156	129	27
	25	144	161	– 17	126	121	5
	50	128	163	– 35	107	122	– 15
	75	128	177	– 49	103	134	– 31
16	0	101	97	4	101	74	27
	25	68	85	– 17	70	65	5
	50	44	79	– 35	44	59	– 15
	75	29	78	– 49	29	60	– 31

SHORT DISTANCE CABLE CRANES.

65% of the productive forest area of Norway belongs to farmers. We have developed light cable cranes which may be mounted as additional equipment on farm tractors. Such cable cranes are suitable for distances up to 300 meters but the optimum distances are between 50 and 200 meters.

For shorter distances we have developed a remote controlled single drum or double drum winch for farm tractors. The tractor operator pulls in a tractor load of stems or unbranched trees. The load is ground skidded by the tractor to the landing. The remote control is of great help for the worker when he fells, sets the chokers and controls the winch. We use two systems: A radio transmitter and receiver system or a system with infra-red control of a similar type as is used to operate TV-sets.

2/3 of the winch and cable crane terrain in Norway may be logged by short distance cable cranes. In long hillsides, a dense road network is needed. The spacing should be 400-500 meters (preferably truck-roads).

On short distance cable cranes the crew is normally 2 men. One of them operates the winch and unhooks the chokers on the landing. The other man takes care of the felling and choker setting in the terrain.

If the limbing and bucking is done by chainsaw the feller/choker man limbs the tree using his chainsaw on the upper side (2/3 of the limbs). The winch operator cuts off the rest of the limbs and bucks the trees at the landing.

Full tree yarding is often used. In this case the terrain-worker fells the trees and sets the chokers while the winch operator releases the chokers on the landing. They bring together piles of unbranched trees along the truckroad. A contractor with a delimbing machine takes care of the conversion from unbranched trees to logs. His work starts when the yarding crew has left the area. The contractor harvests the trees in the piles along the truck road.

The earlier short distance cable cranes used fixed skylines. This system is now not in use because the rig up time is too high. Interlocked winches and running skylines have replaced the previous fixed skyline cranes.

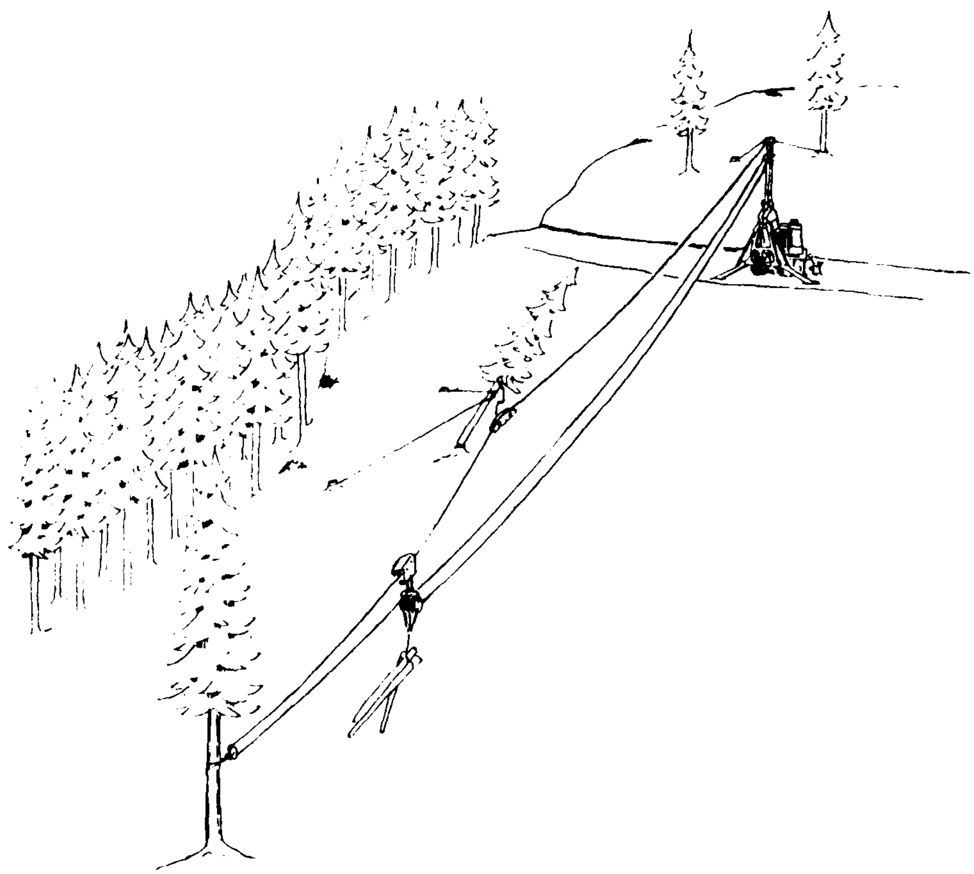


Figure 8. The Owren Vario Winch as running skyline with support on the haul-back line.

Figure 9.

The Owren Vario Winch.

THE OWREN VARIO WINCH.

Owren Vario winch is produced by Trygve Owren Mechanical Workshop, Vingrom. The cable crane is a result of cooperation between the company and our institute.

This cable crane is suitable for small contractors. It is a hydrostatically driven 3-drum winch (main drum, slack pulling drum and haul-back drum). Due to losses in the hydraulic system the interlocking only covers 30% of the power. This is also an advantage since it reduces the danger of overloading and breakdowns during operation. The winch may be mounted on a small 40 kW crawler tractor (fig. 9). The winch may also be mounted on an articulated frame steered skidder (fig. 10) with at least 50 kW.

The hydrostatic drive is a 2 speed system. The lowest speed varies from 0 to 2.6 meters per second and the highest from 0 to 4.9 meters per second (middle drum diameter). The line pull varies between 18 and 26 kN (low speed) and 10 to 15 kN (high speed). The tip tower is 6.5 meters high and it may be laid down over the tractor when moving to another logging site.

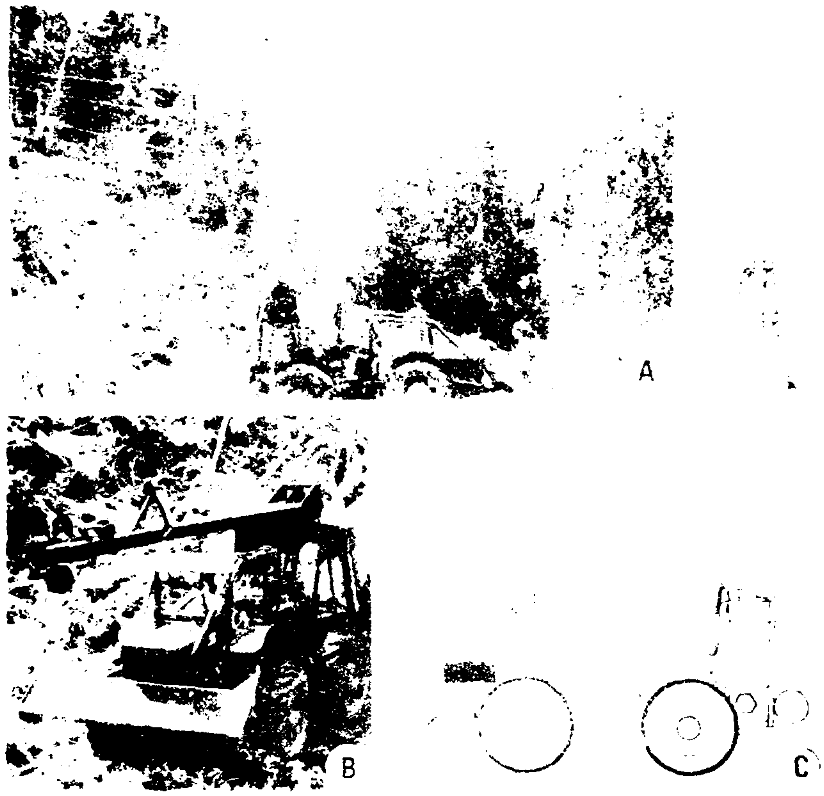


Figure 10.The Owren Vario Winch mounted on an articulated frame steered skidder.

In addition to the 3-drum winch the yarder has a mechanically driven double drum winch - one drum for a straw line and the other for a guy line. Only one guy line is used. Sideways stability is provided by 2 hydraulically operated side feet.

The carriage is of a similar but smaller type as used on the Moxy winch. The drum in the carriage has three parts. The hoist line is coiled on the central part. The main line is running in on the upper side of the right part and the slack pulling drum on the lower side of the left part of the winch drum. This makes it possible to pull in or out the hoist line by moving the main and slack pulling lines in relation to each other.

THE IGLAND INTERLOCKED WINCH.

The double drum interlocked winch is placed at the low end of a 5 meter high telescope tower. The winch and tower unit can be connected to the 3-point coupling on a farm tractor. The speed of the main line in relation to the haul-back line can be continuously adjusted by means of a belt variator as shown in fig.11.

The winch is driven by the power take off on the farm tractor. A 50 kW farm tractor is sufficient for the job.

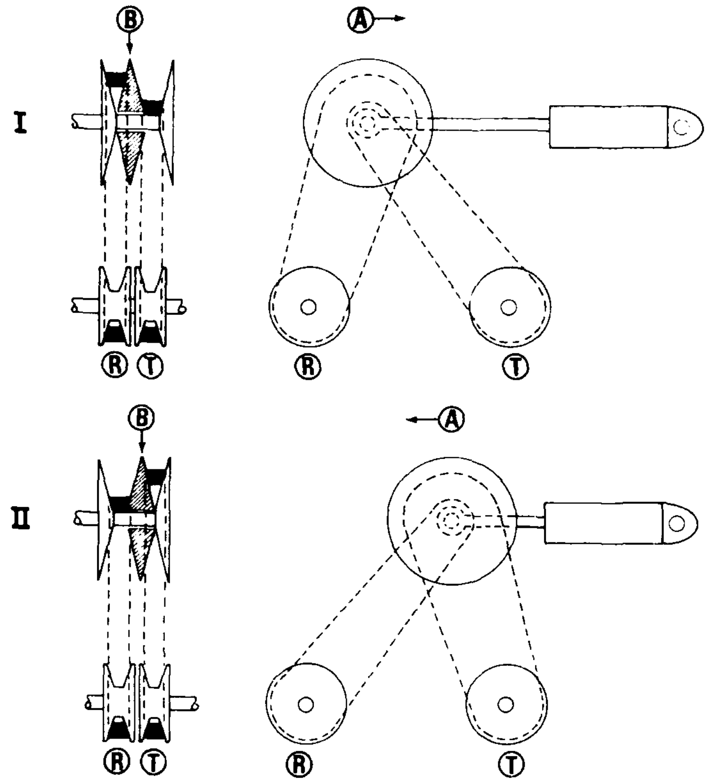


Figure 11. The belt variator in the Igland interlock winch.

The telescope tower must be stabilized by 3 guylines - one main guyline opposite to the yarding direction and two side guylines to avoid a side tipping. The farm tractor may be disconnected from the tower and winch as shown in fig. 12 . The winch as well as the cable crane remain on the logging site while the tractor moves away, for example back to the farm.

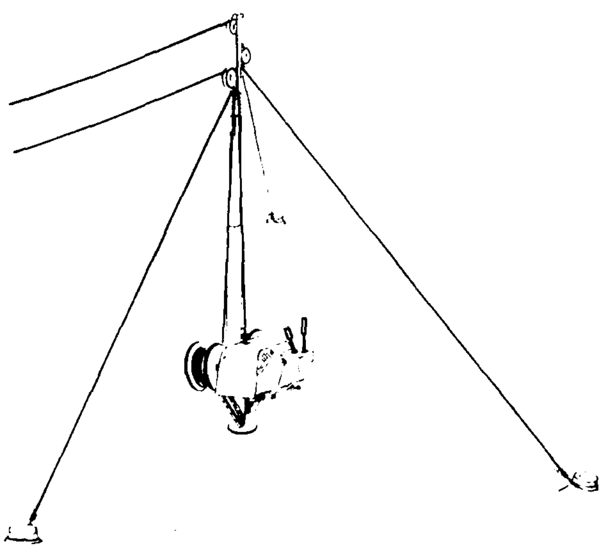


Figure 12. Igland Interlock winch with telescope tower. The farm tractor may be disconnected and moved away while the cable crane remains rigged up.

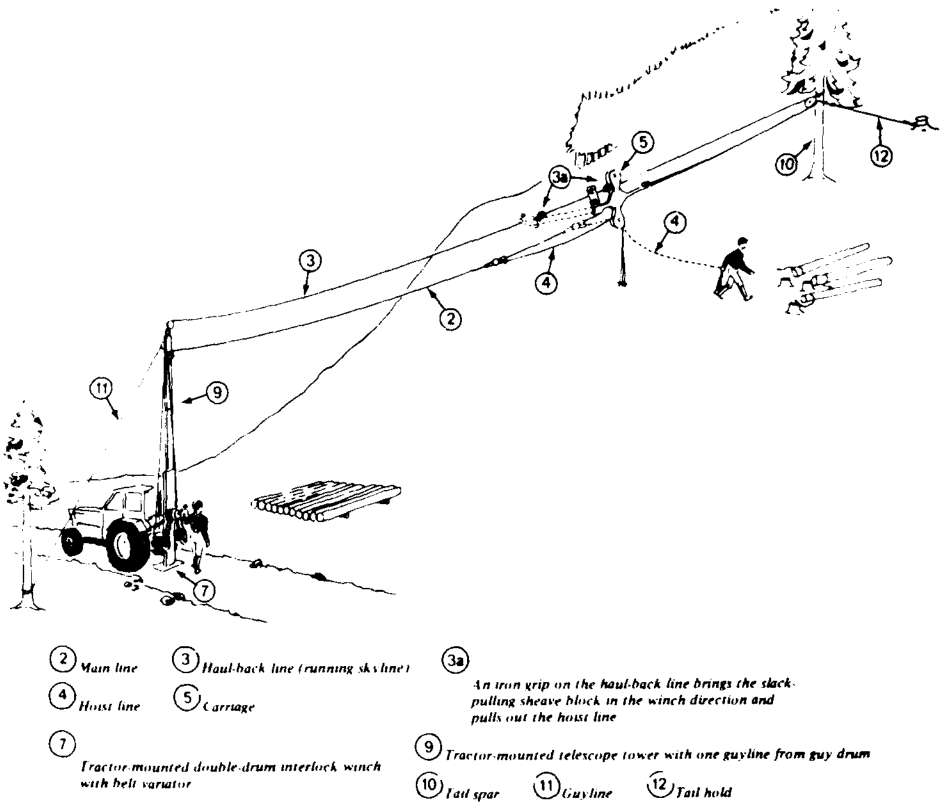


Figure 13. Cable crane yarding with the Igland Interlock winch and carriage with a slack pulling block.

Since this winch has two drums only, a special carriage is needed in order to pull out the hoist line. One method is illustrated in fig. 13. The hoist line is fixed to a 3-way swivel on the haul-back line. On the haul-back line there is a "steel egg". When the carriage reach the logging area, the "steel egg" pulls the slack pulling block in the direction of the winch so that the slack pulling line brings the swivel toward the carriage. It is easy for the terrain worker to pull out the slack hoist line. When all trees or logs are yarded from one place in the hillside, the terrain worker loosens the steel egg, and move it about 15 meters to the next yarding place, where the "egg" is fastened to the haul-back line again. Self releasing chokers may be used together with this system as well as with Owren Vario Winch.

Another method for simplifying the pulling out of the hoist line is illustrated in fig. 14. The carriage is shown in fig. 14. A "steel egg" is fixed to the main line. When a load has been brought to the landing, the carriage returns in the terrain direction until the "steel egg" has passed the carriage. The "steel egg" fastens in the carriage (fig. 14) which can return to the terrain with the hoist line already pulled out (fig. 14). After the chokerman has set the chokers he releases the "steel egg" in the carriage in order to start the lateral skidding.

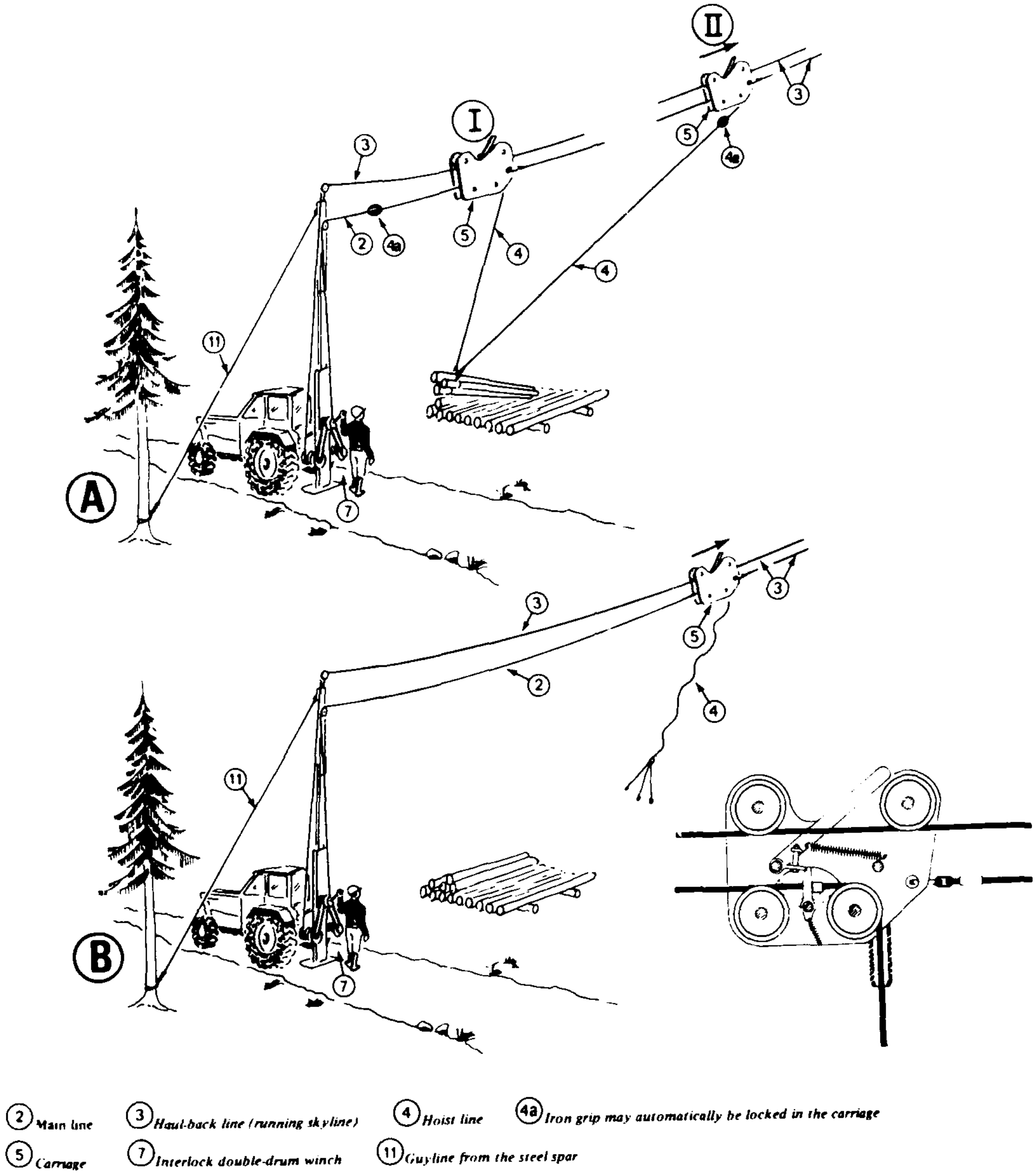


Figure 14. The Igland cable crane with interlock winch and carriage with fixed length hoist line.

A. When the load is lowered to the landing (A.I), the carriage is moved outwards (A.II) until the iron egg on the main line is fastened in the carriage.

B. The empty carriage returns to the felling site with the fixed length hoist line pulled out.

SUPPORTS FOR RUNNING SKYLINES.

The Norwegian Forest Research Institute has developed a support for running skylines.It is illustrated in fig. 15 and 16. The carriage may be used together with a drum carriage for a triple drum interlock winch or the other carriages for double drum interlocked winches.

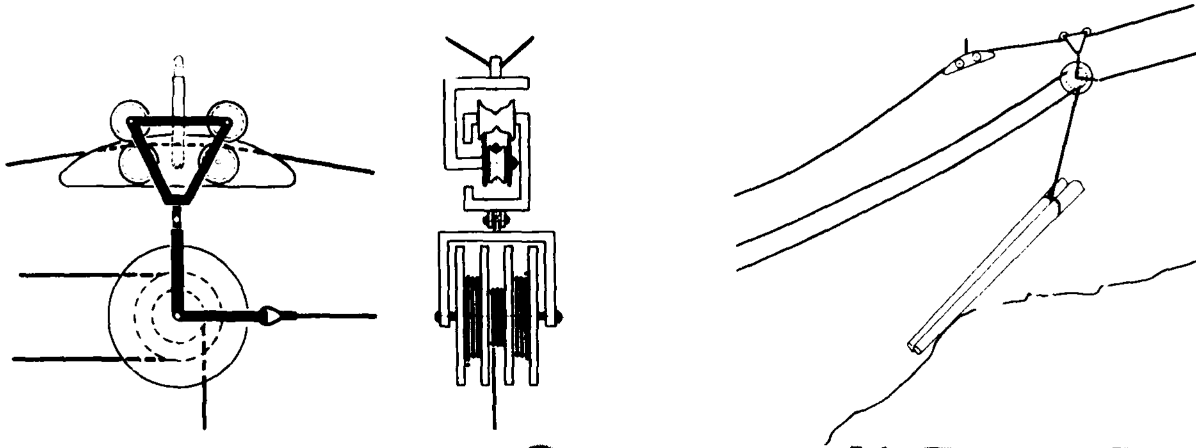


Figure 15.

Support for running skyline

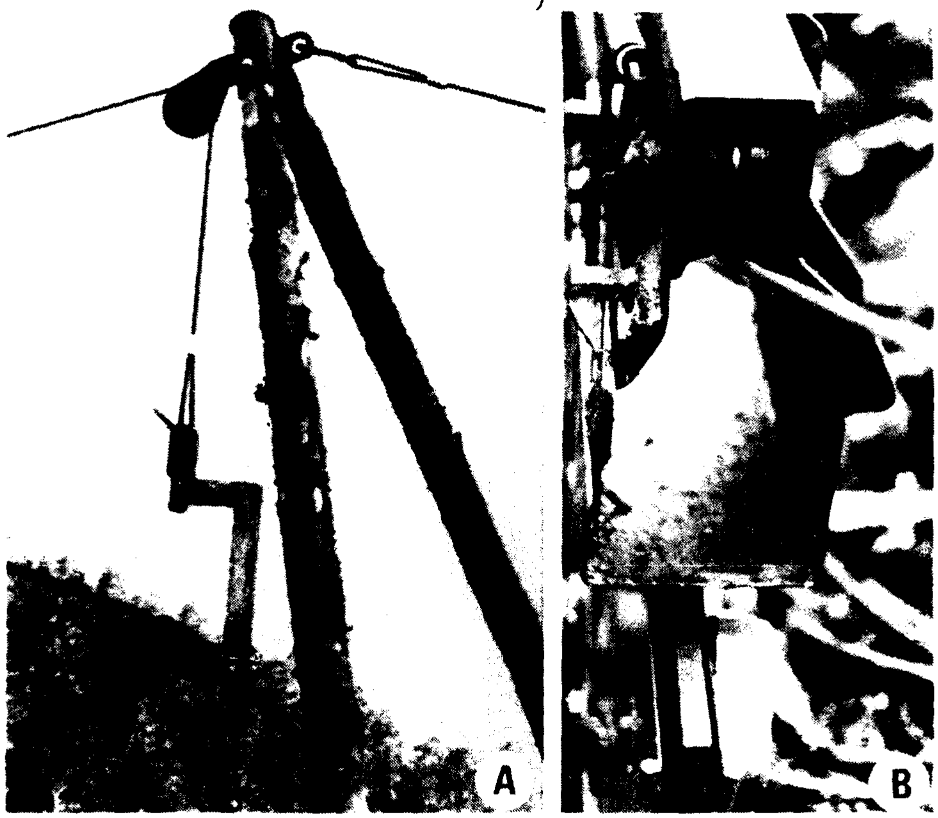


Figure 16.

A. The cable shoe with the haul-back line.
B. The top of the carriage.

SELF RELEASING CHOKERS.

The Norwegian Forest Research Institute has made many experiments with different types of self-releasing chokers. The best one is illustrated in fig. 17. The functioning of the release mechanism depends on the angle between the hoist line and the stem. When the hoist line is perpendicular to the log or in a forward direction the choker is kept in position. As soon as the load has reached its place on the landing the carriage is lowered and by returning it in the direction of the terrain, the angle of the hoist line releases the choker automatically. This system works without any problem for one or two chokers, but there are difficulties when three chokers are used. The chokers twist and cause problems. These automatic chokers should only be used when yarding trees over 0.4 cu.m./tree.

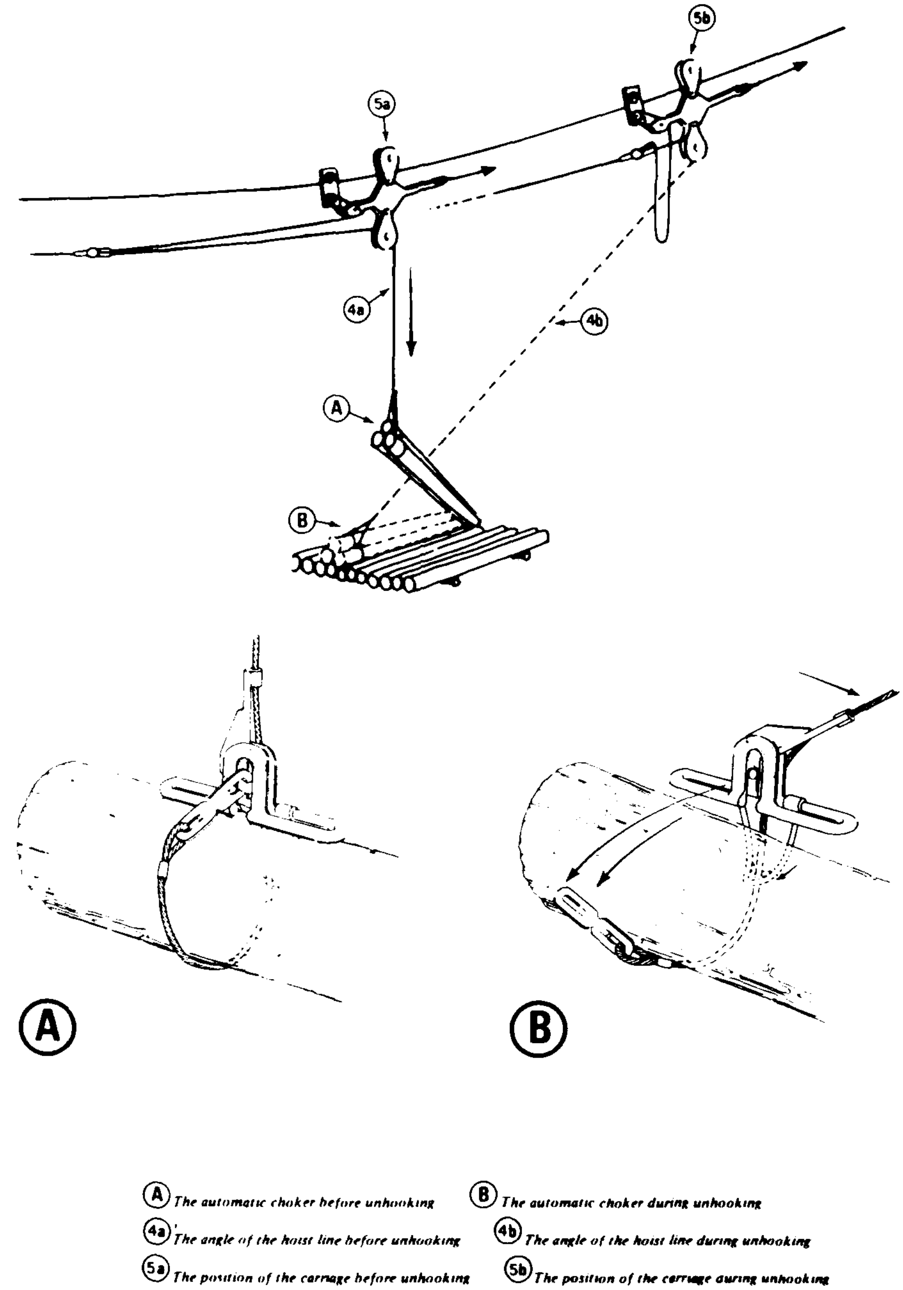


Figure 17. The Igland choker for automatic unhooking of logs on the landing.

THE VARIO-CRANE 6912.

Based on experiments with various cable crane systems carried out by the Norwegian Forest Research Institute, the Vario-Crane has been developed in co-operation with Owren Mechanical Workshop, Vingrom. The Company will now start production of the machine.

The Vario-Crane is built on a crawler tractor chassis. It is powered by a 79 kW engine and the machine can be used either as a running skyline system or as a live skyline system.

When the machine is used as a yarder for running skyline, the main-, haul-back- and slack pulling lines have a dimension of D = 12 mm (1x26+1). This dimension allows for a running skyline span of 300 meters.

When the machine is used as a yarder for the live skyline system the main line, haul-back line and slack pulling lines are D = 10 mm (1x26+1) and the skyline is D = 18 mm (1x26+1). The live skyline may be used on distances up to 500 meters. (Main line, slack pulling line and skyline 500 meters, haul-back line 1 000 meters). In addition there are two guy line drums with 75 meters guy line D = 16 mm. There is one drum for a 2 mm rig up line and one drum for a 4 mm rig up line. During rigging the haul-back line is used as a straw line.

The line speed varies between 0 and 4.3 meters per second and the maximum main line pull is 27 to 40 kN.

The crew consists of one winch operator and two choker setters who also carry out the felling. The unhooking of chokers at the landing is carried out by the winch operator. We are experimenting with remote control of the winch. The winch operator can work as chaser man and at the same time operate the remote control of the yarder.

The research operation with the Vario-Crane is successful and promising.

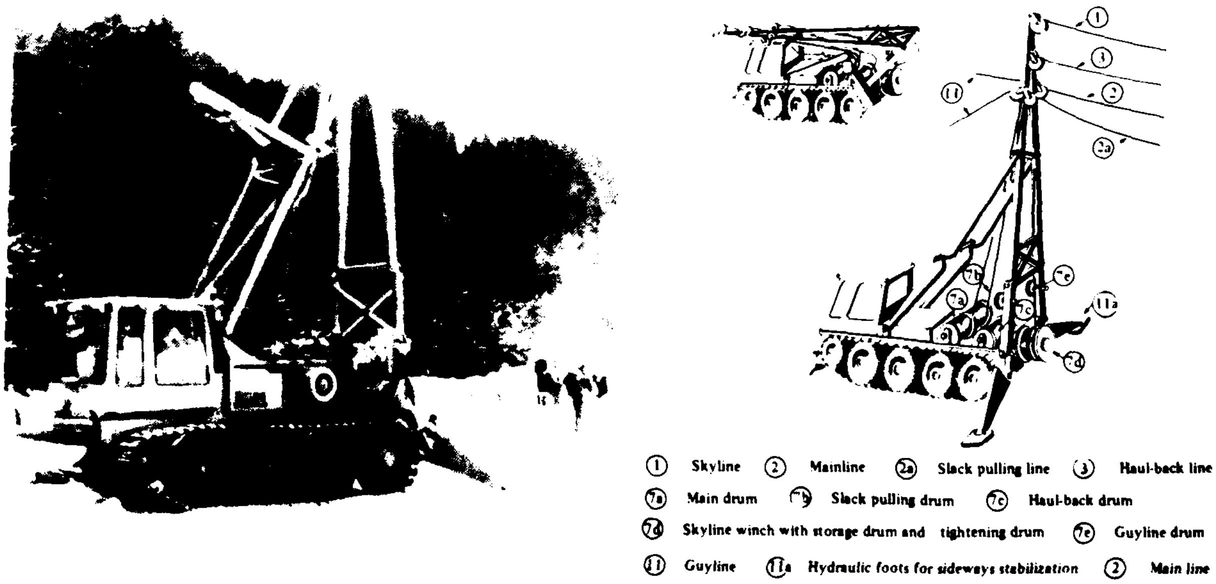


Figure 18. Owren Vario-Crane with the tilt tower rigged up and laid down.

YARDING PRODUCTION.

The Norwegian cable crane terrain has mostly a rough surface with cliffs, boulders and other obstacles. The surface is seldom smooth such as in the Austrian or Swiss Alps. Often the limbing and bucking is being done at the landing by a limbing machine.

Table 3. Productivity (manhours per cu.meter) and production for the crew. (cu.meter per work place hour). 0.3 cu.m. per tree.

Medium distance cable cranes:

Moxy = Moxy running skyline
Nestestog = Nestestog radio-steered cable crane.

Short distance cable cranes:

Vario Winch = 3-drum running skyline
Igland = 2 drum running skyline
Igland uphill = Shot gun cable crane

	F=Felling y=yarding	Yarding distance meter (sydist)	Man hrs/cu.m.		Crew no. of men	Production for the crew cu.m/hrs
			Yarding	Rigging		
Moxy	y	100 200 300	0.28 0.35 0.43	0.13 0.13 0.13	4	9.8 8.3 7.1
Moxy	F+y	100 200 300	0.52 0.65 0.74	0.13 0.13 0.13	5	7.6 6.4 5.7
Nestestog	F+y	100 300 500	0.43 0.62 0.83	0.14 0.14 0.14	4	7.0 5.3 4.1
Vario Winch	F+y	50 100 150	0.29 0.38 0.47	0.10 0.10 0.10	2	5.1 4.2 3.5
Igland	F+y	50 100 150	0.30 0.37 0.44	0.12 0.12 0.12	2	4.8 4.1 3.5
Igland uphill	F+y	50 100 150 200	0.27 0.31 0.35 0.39	0.10 0.10 0.10 0.10	2	5.4 4.9 4.4 4.1

The spruce and pine trees are branchy. They are mixed with some birch and poplar. In mature stands clear fellings are used. The tree dimensions vary between 0.2 cu.m. and 1 cu.m. per tree. The average tree dimension is 0.3 cu.m. per tree and the production figures in table 2 are typical for such tree dimensions.

The Moxy cable crane has a 5 man crew (1 foreman, 1 winch operator, 2 chokermen and 1 chaserman). In addition there is one operator at the limbing machine.

Short distance cable cranes are usually operated by two men (one winch operator who also does the unhooking and one choker man who also fells the trees).

The long distance cable crane works up to 500 meters and the short distance cable crane are typical for up to 200 meters yarding.

The production is given per hour of the work place time, which is the effective time + the normal delay times when working on the logging area. One has to add approximately 25% to the work place time to get the total working time for the crew. The production in cu.meter per work place hour for the crew (the cable crane) as well as the productivity in man hours per cu.m. is given in table 3. This includes yarding and in some cases yarding and felling. The long distance cable cranes always use a limbing machine on the landing for limbing and bucking. In Norway the work place time is normally between 6 and 7 hours per 8 hour day, depending on the conditions.

RIG UP METHODS.

The logging volume on each set up is small in Norway. The tree dimensions are small. The terrain conditions varies and so does the site conditions. In a sustained yield forestry as practiced in Norway the site clear fellings are small in order to adjust the silvicultural programme to the local terrain-, soil- and ownership conditions.

In order to meet these challenges the yarder must be mobile and the rig up time as little as possible.

Planning.

The transport network must be laid out and built before the cable yarding starts. As soon as the silvicultural programme has been decided the logging areas are pointed out on aerial photographs and for the medium distant cable cranes the skyline and possible landing supports and anchoring points are marked on the photographs. The foreman starts his work on the logging area before the yarding crew arrives. He may have a cutter with him to cut corridors for the lines. He also lays out a 2 mm rig up line along the skyline corridor. He can easily carry 1 000 meters of the line on a backpack spool (rucksac spool). The foreman prepares the anchors for the guylines and the tail hold before the logging crew arrives on the logging area. This preparatory work is done to shorten the rig up time for the yarder and the crew.

Useful equipment.

A rig up ladder is used instead of climbing shoes when rigging up a spar tree, a tail tree or supports. The rig up ladder is constructed in 3 m long sections which are easy to carry. The ladder is fixed to the tree by a chain. The worker climbs the first ladder and puts the second one on the top of the first one. He then fixes this ladder to the tree. The rig up ladder creates less strain on the workers and is faster to work with than climbing shoes (fig. 19).

Figure 19.

Rig up ladder on a finger support.

Rig up winch. In many cases a rig up winch is used to move the tail block from one skyline corridor to the next. A chain saw winch has been used. It can be carried by two men. The pull is 9 kN with a speed of 0.2 meters per second.

Figure 20.

The JoBu chain saw winch (left) and the Ackja rigging winch (right)

The Austrian Ackja rigging winch is a better solution. The weight is 750 N and the pull is 8 kN with a speed of 0.8 meters per second (D = 6.5 mm, L = 100 meter).

Rig up lines have two dimensions: one has a diameter of D = 2 mm and the second has a diameter of D = 4 mm. It is easy for the foreman or others in the crew to carry the first rig up line and lay it out along the skyline corridor. The second rig up line (D = 4 mm) can be pulled out by the thin one and the 8 mm thick straw line is then pulled out by the second rig up line. This method gives little strain on the workers and shortens the rig up time.

Figure 21.

The double backpack spool with 1 000 meters of 2 mm rig up line

A tail block swivel is a good help when taking out twists between the lines during the first rig up on a logging area. The swivel can be fixed in four positions by a bolt.

After the skyline has been rigged up the winch operator moves the carriage slowly towards the tail end of the cable crane. It is then easy to take out the twist by turning the block. When the twist has been taken out the bolt in the swivel fixes the tailblock in the correct position.

We try to avoid rope clamps which are tightened by screws. Instead we use grips, fast couplings, knots etc. such as single wedge grip, double wedge grip eccentric pressure grip or wedge pressure grip.

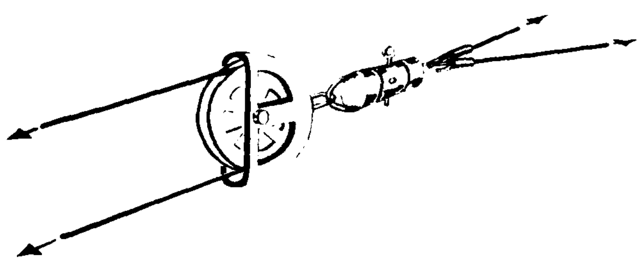


Figure 22.

The tailblock swivel.

RIGGING UP MEDIUM DISTANCE CABLE CRANE.

The working technique during the rig up operation varies with the equipment and terrain conditions. As an example I may describe the rig up method of a Moxy running skyline cable crane which shall yard the timber from a mature forest on the upper side of a road (fig. 53-58). The yarding is carried out on 20 m wide corridors. The lateral skidding takes place only from one side of the skyline.

The skyline is first rigged up along the edge of the mature stand. The crew fells and yards a 20 meter wide area and transports the timber from the stand to the landing near the roadside.

As soon as one 20 meter wide area along the stand has been felled and yarded, the skyline is moved sideways to the new edge of the mature stand. The movement of the yarder along the truck road is carried out by the winch operator while the movement of the tail block is carried out by the foreman, sometimes helped by one of the fellers/choker setters. The rig up takes place in the following steps:

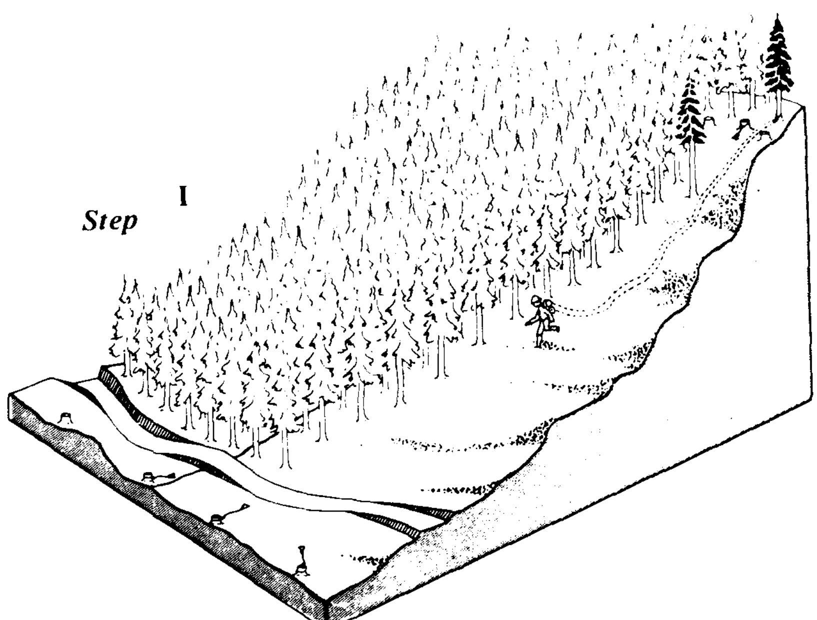


Figure 23.

Step 1. The foreman walks out with the 2 mm rig up line on backpack spools. He walks to the top of the hillside, splices the 2 ends of the rig up line and places it around a small tail block. The two parts of the rig up line are laid out along the skyline corridor while the foreman walks downhill.

The foreman also chooses the anchors for the tailhold and places the anchoring straps. The same is the case with the anchors for anchoring the tower on the yarder.

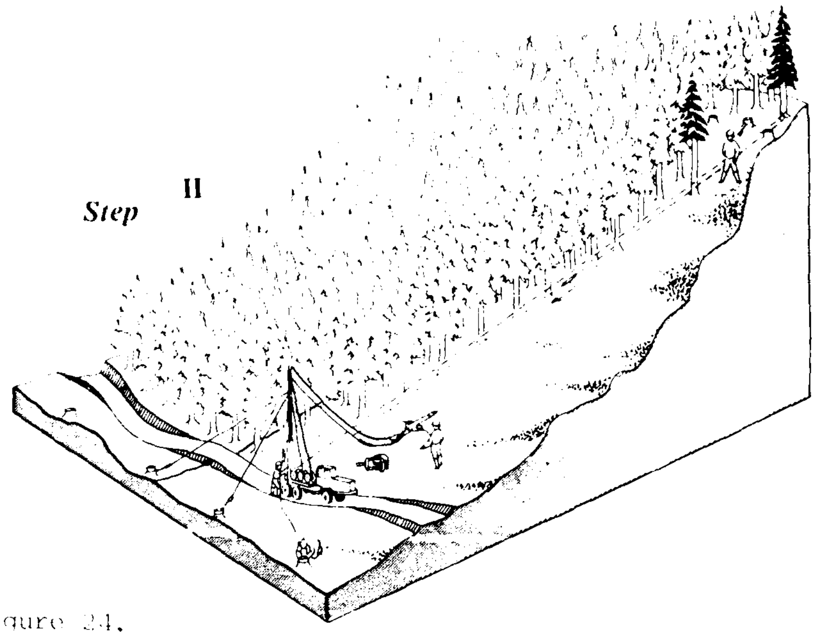


Figure 24.

Step 2. When the foreman has prepared for the rig up, the crew with the yarder arrives at the logging area. The 4 mm rig up line is pulled out by the 2 mm rig up line, and the 8 or 10 mm straw line is pulled up and down again by the 4 mm rig up line. In the meantime the two choker setters have attached the guylines on the steel tower to the anchoring points.

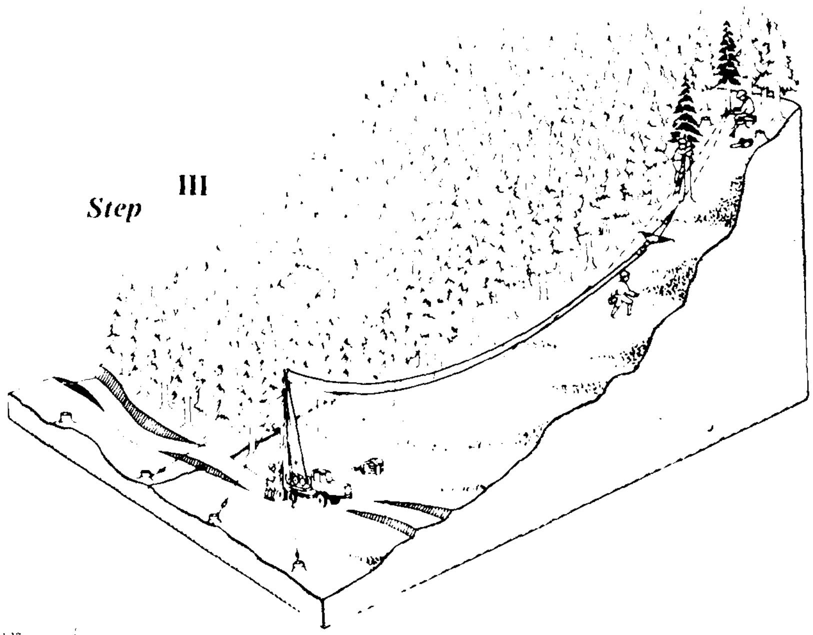


Figure 25.

Step 3. The tackl with the tailblock is pulled out to the tailhold with the straw line. The foreman and one of the choker setters fasten the tail tackle to the anchoring straps while the winch operator and the other choker setters place the carriage on the lines.

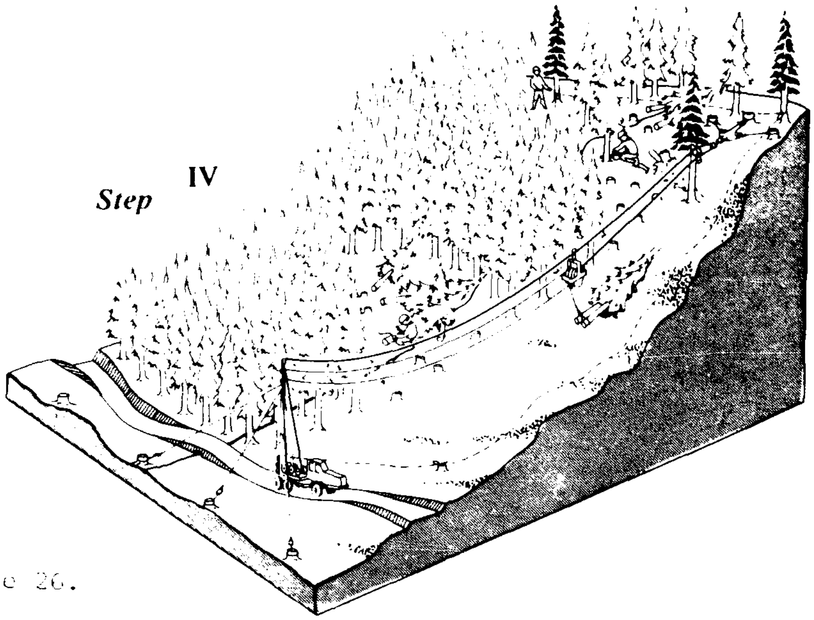


Figure 26.

Step 4. When the carriage is ready the lines are tightened by the winch operator. If there is twist between the two parts of the haul-back lines the carriage is being moved slowly towards the tail end. By taking out the bolt in the swivel the tail block can be turned around in order to take out the twist. The transport can start, one feller high up in the hillside and another lower down in the hillside. They are felling and setting the chokers every second turn.

While the felling and yarding go on the foreman prepares a new anchor and tailhold. He has an extra tail tackle and rigs it up on the new corridor. He also prepares new anchors if necessary for the new position of the yarder.

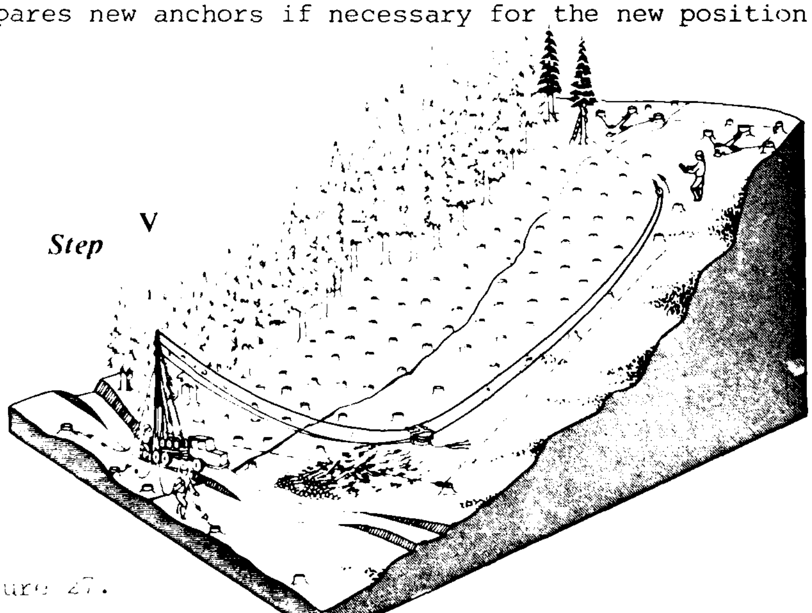


Figure 27.

Step 5. When the first 20 meters wide area has been logged the corridor change takes place. The tail block is moved from the tail tackle on corridor no. 1 to the tail tackle on corridor no. 2 by means of the straw line. He may reguire help from the upper feller/choker setter during this work.

In the meantime the yarder operator and the feller (choker setter) who works closest to the yarder, moves the yarder and changes the guylines to the new anchors. When this has been done the winch operator tightens the skyline and the crew starts felling and yarding on the new 20 m corridor. The foreman starts immediately to prepare for the next corridor change.

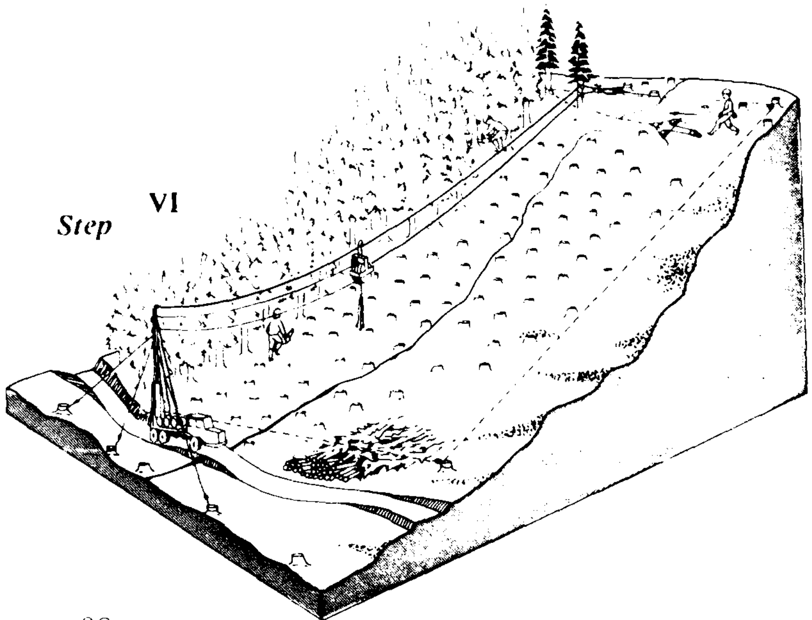


Figure 28.

Time for rigging up, rigging down and corridor changes.

The normal performances during rigging and corridor changes are summarized in table 3 for the Moxy cable crane. The crew consists of 5 men (one foreman, one winchoperator, chaser man and 2 fellers/choker setters).

The rig up time takes place when starting on a new logging area. The rig down time takes place after the timber has been yarded at the end of the operation. The time for road change is the movement of the cable crane 20 meters sideways from one corridor to the next.

Table 4. Moxy running skyline.
Rigging up and rigging down times and corridor changes in hours for a 5 men yarding crew.

	Length of cable crane, meter		
	100	300	500
	Hours for the crew		
Rigging up time	0.70	2.10	3.50
Rigging down time	0.14	0.50	1.50
Total rigging time	0.84	2.60	5.00
Corridor change	0.24	0.42	0.60

RIGGING UP SHORT DISTANCE CABLE CRANES.

The operational method for the short distance cable cranes is approximately the same for the Owren Vario Winch and the Igland Interlock Winch. They are operated by two men. One of them operates the yarder and unhooks the chokers while the other is setting the chokers.

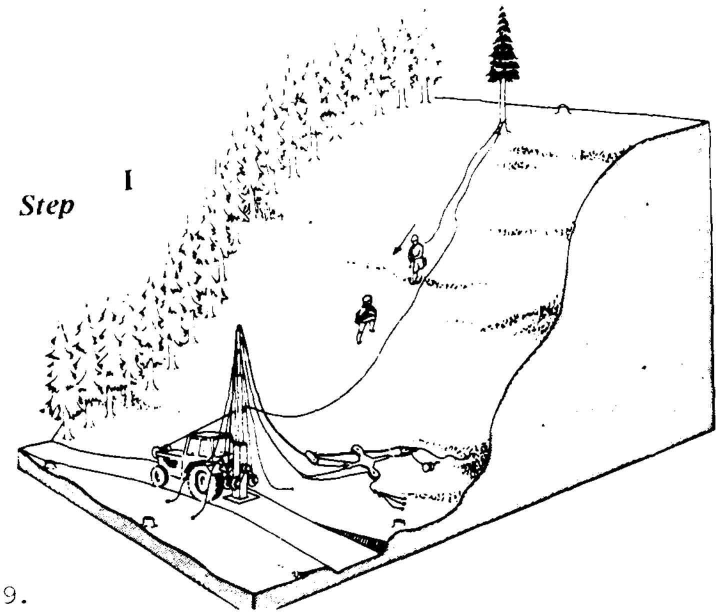


Figure 29.

Step 1. The choker setter walks out with the straw line, fixes the tail block to the tail tree and starts to walk downhill again. The winch operator starts to rig up the yarder and walks uphill to meet the choker setter midway between the winch and the tail tree.

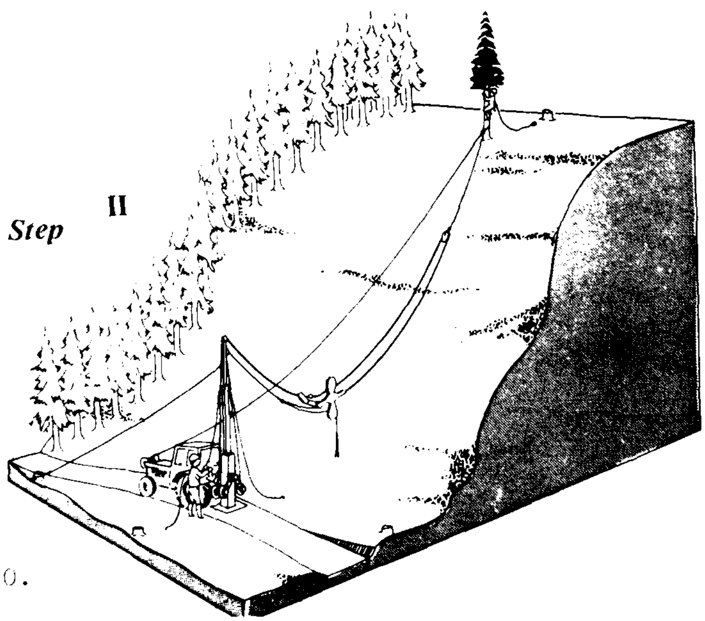


Figure 30.

Step 2. The choker setter returns to the tail tree and rigs it up. The winch operator walks down with the straw line fasten it to the tail block and pull out the tail block with the haul-back lines. The choker setter continues to rig up the tail tree.

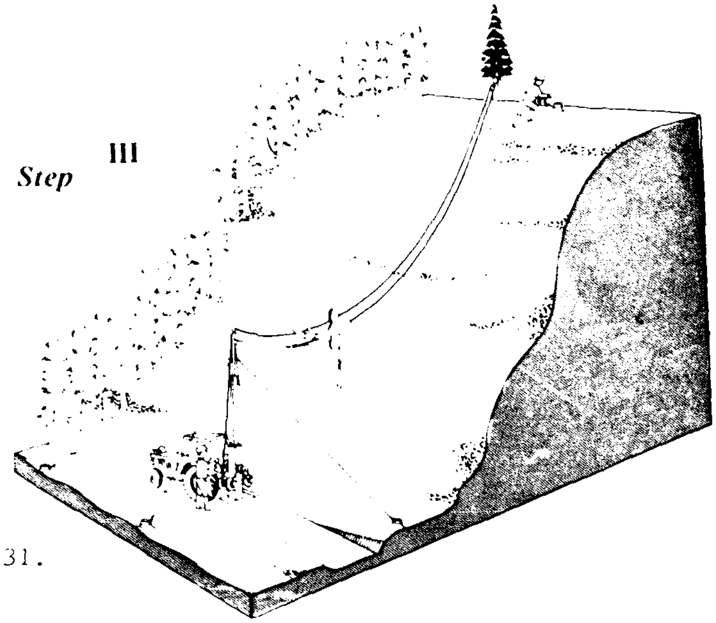


Figure 31.

Step 3. The choker setter finishes the rigging of the tail tree and the winch operator finishes the rigging of the tower on the yarder. He moves the carriage slowly towards the tail tree. Twist in the haul-back line may be taken out by turning the tail block in the tail block swivel.

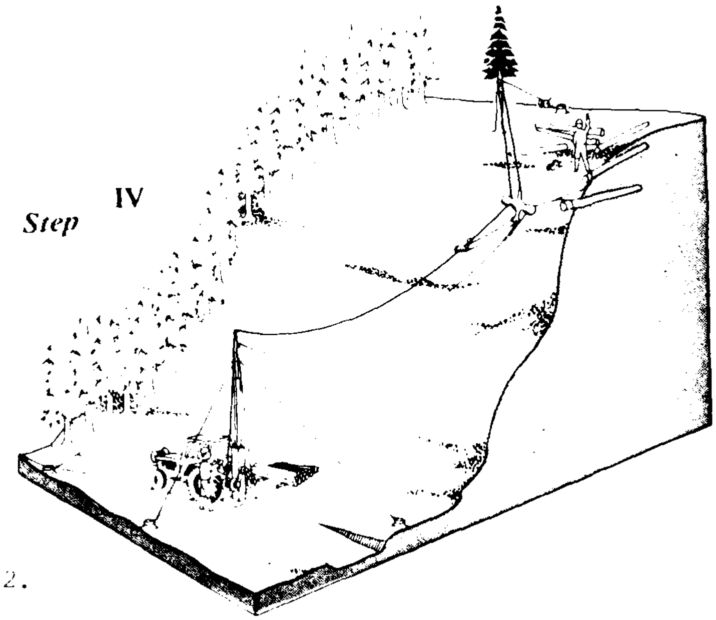


Figure 32.

Step 4. The yarding starts. As soon as one 20 meter corridor has been yarded the corridor change takes place, 20 meters at the time.

A two man crew takes usually two hours to rig up a 100 meter cable crane. The same two man crew uses on average 0.6 hours for a corridor change (20 meter sideways parallel to the first skyline corridor).

HELICOPTER AND BALLOON LOGGING.

An extensive research programme on helicopter logging was carried out in Silvimontana, the logging research forest in Telemark during the period 1963 to 1970. The wood was cut, barked, piled in bundles in optimum size for the helicopter and dried. The timber was transported by helicopter downhill to a lake for floating (river drive). The hight difference varied between 400 and 700 meters and the transport distance between 1 and 4 km. During these years we tried different helicopters: Bell 204 B (lifting capacity 1.6 ton), Sikorsky S 61 (lifting capacity 2.6 ton), the USSR helicopter MI-6 (lifting capacity 8 ton). We found that the smallest helicopter gave the best result since it was easier to bundle small helicopter loads than big ones on the logging area. The helicopter transport could not compete economically with cable logging. The cost was up to twice as much as the cost for logging with cable crane.

In 1980 and 1981 a different method was investigated with Bell 205-A (lifting capacity 1.8 ton). The workers were brought up to the remote and difficult logging area with the helicopter. They felled the trees and set the chokers. The helicopter brought the unbranched trees downhill to the landing where a limbing machine immediately converted the trees to sawlogs and pulpwood. This operation was very efficient. The costs, however, were 50% higher than logging by cable crane.

In 1972 one of our students, logging engineer Hans Anders Svendsen, wrote his thesis at our University on balloon logging. He went to the American Westcoast where Faye Steward received him and he worked at the Bohemia Lumber Company. He took time studies on the Bohemia balloon logging and investigated the possibility of using this method under Norwegian conditions. He came up with a proposal, an onion shaped balloon filled with 3 700 cu.m. Helium gas. The cost calculation showed, however, that this method was more expensive than winch and cable logging in steep terrain.

TRACTOR LOGGING IN STEEP TERRAIN.

The Norwegian Forest Research Institute has carried out investigations on the stability of different types of tractors and their ability to operate under steep and rough terrain conditions. Laboratory tests are combined with operations on test-tracks and investigations on practical tractor logging in various companies. Crawler tractors, articulated frame steered tractors, farm tractors with 2-wheel drive and 4-wheel drive as well as forwarders with 6-wheel drive and 8-wheel drive have been investigated.

The result from these investigations and experiments showed that tractor yarding can safely be carried out on forest terrain where the slope is less than 40%. In steeper terrain a network of tractor roads is needed if tractor yarding shall be used. Without roads, cable yarding is the best solution.

Much of the terrain surface in Norway is full of boulders, cliffs and other terrain obstacles. If this type of terrain is steeper than 40% winch or cable logging has to be used.

Locally the steep hillsides have a smooth surface with deep soil where it is easy to build tractor roads. The tractor roads are laid out parallel to each other and parallel to the terrain contours with a spacing of approximately 40 meters (terrace roads). The wood may be ground skidded downhill to the tractor by a single drum or double drum tractor winch.

The load is then ground skidded along the tractor road to the landing.

Figure 33. 40 m spacing between the feeder roads, and downhill gravity rolling of logs.
A. The forwarder loads the logs from the upper side of the feeder road with a knuckle boom loader.
C. The forwarder with double boggie.
B.and D. Skid-stems fixed to the 70 cm high stump.
E. Feeder roads parallel to the terrain contours

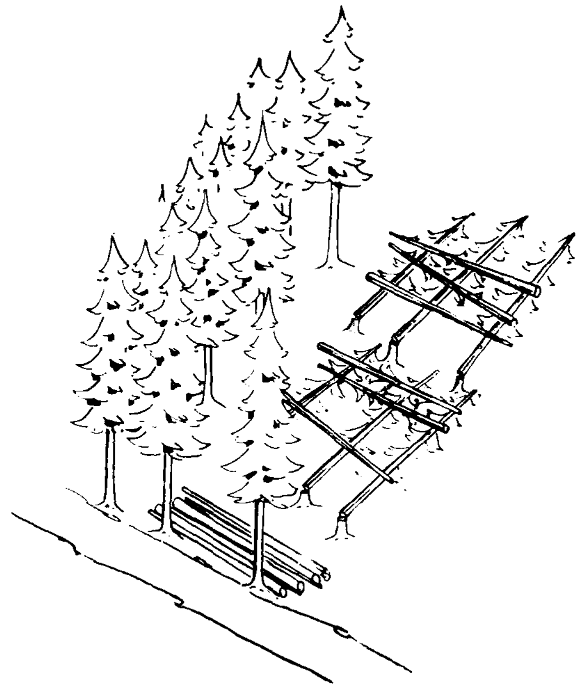


Figure 34.

Downhill rolling of stems on skid-stems to a pile near the feeder road.

Under smooth ground conditions, gravity-rolling may be used instead of winching. First, a few trees are felled uphill on 70 cm high stumps. The trees must not be completely sawn off the stump. They must remain fixed to the stump after felling. These trees are limbed on the upper side and used as skid stems on which the downhill rolling can be carried out (fig. 34).

The trees on the logging area are felled over the skid stems and limbed by chainsaw. Afterwards they are rolled sideways downhill on the skid stems until they turn against the buffer trees along the tractor road. Here, they are bucked into assortments. A forwarder with a knuckleboom loader collects the timber and transports the load along the tractor road to the truck road. This method needs well trained workers but is very efficient and economic.

The method with terrace-roads may increase danger of erosion. If the soil consists of good gravel tractor logging on terrace roads may be used on slopes up to 70%. If the terrain is steeper cable crane logging has to be used.

CONCLUSIONS.

1. Helicopter logging and balloon logging are more expensive than winch and cable logging.

2. Helicopter logging reduces the need for access roads, and the operational activities are limited to harvest of mature timber only (mining). A road network is necessary in order to carry out all operational activities in a sustained yield forestry programme.

3. Tractor logging is always cheaper than cable crane logging, if no road building is needed.

4. When the slope is less than 40% tractor logging can take place without any road building.

5. When the slope is between 40% and 70% and there is smooth surface and deep soil (low building costs for tractor roads), tractor logging can take place on terrace roads with 40 m spacing.

   a) Skidder or farm tractor with single and double drum winch. The trees or stems are pulled by the winch to the tractor and ground skidded along the terrace road to the landing.

   b) Forwarder with nuckleboom loader. The stems are rolled sideways and downhill to the terrace road where they are bucked, loaded on the forwarder and transported along the terrace road to the landing.

6. Medium distance cable cranes between 300 and 400 meters (max. 500 meters) are the best solution on very rough terrain and where the cost of road building is very high (Terrain with cliffs, boulders etc. steeper than 40% and all terrain steeper than 70%). The spacing between the feeder roads (parallel to the terrain contours) should be 800-1000 meters.

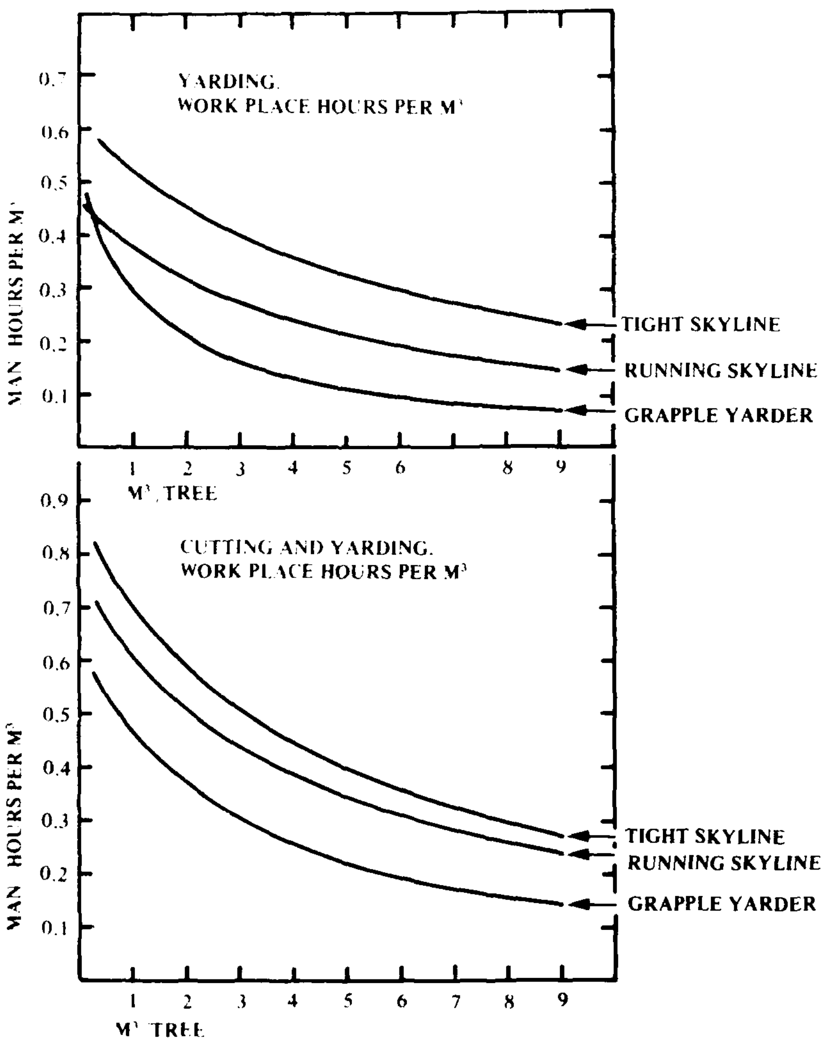
7. The terrain conditions in point 6 may be logged by short distance cable cranes with a range of 200 meters, when the road building is easy and the building costs low. The spacing between the feeder roads should be 400 meters.

8. A dense road network (truck roads) is an advantage from a silvicultural point of view. Light two-men operated cable cranes may be used. Small volumes may be taken out on each logging area. This allows for a silvicultural programme which can vary according to the variation in forestry conditions.

   65% of the total forest area in Norway belongs to farmers. On their land, a dense road network facilitate the use of light cable cranes for farm tractors.

9. The feeder roads branch out from the access road which has to be as steep as possible in order to overcome height differences in mountainous forests. Research carried out by The Norwegian Forest Research Institute has shown that downhill truck transportation of 30 cu.m. loads can safely take place in the summer on roads with a gradient of up to 22%. Spraying asphalt

emulsion on a gravel road reduces the climatic erosion due to rain fall etc. (2 litre asphalt emulsion per sq.m.).



Figur 35. The average productivity in manhours per cu.m. for yarding and for cutting and yarding. The productivity is the average of 85 cable systems in Japan, Sovjet Union, Central Europe, Northern Europe, United States and British Columbia.

CLOSING REMARKS.

The organizers of this meeting have asked me to concentrate on Norwegian experiments in Mountain logging. In connection with a book on forest operations under mountainous conditions which I am writing and which will be published by an international publisher in the near future, I have investigated winch and cable systems in the various countries in the world (Japan, the Soviet Union, Central Europe, Northern Europe, United States and Canada). 85 systems in the various parts of the world have been analysed and this has led to rather interesting conclusions which will be published in the book.

It is rather interesting to analyse the productivity of the systems and I have given some of the conclusions in table 3. The productivity is given for yarding only, and for cutting pluss yarding in man hours per cu.m. (work place time).

When comparing the productivity figures from the Norwegian cable systems with the average productivity figures from the world wide range of cable systems it is seen that the Norwegian systems have a rather high productivity. We also see that grapple yarding is a very good method for tree dimensions greater than 1 cu.m. per tree. Cable systems with few men, for example the Norwegian short distant cable cranes lead to a high productivity. This means that a dense road network is of importance both from a silvicultural point of view (small operations on each spot), and from a productivity point of view.

It is also clear that when logging small tree dimensions (less than 0.5 cu.m. per tree) it would lead to considerably increased production, if the trees could be bundled in yarding loads on the logging area. Research and experiments of new methods in this field should be very welcome. This would also be of importance when cable systems are used for thinning operations.

STEEP TERRAIN HARVESTING - AN INDUSTRY PERSPECTIVE

by

John E. Buckhalt

ABSTRACT

The experience of Owens-Illinois in steep mountain logging in the Blue Ridge Mountains of Virginia over the past thirty years is described. The logging technique has changed from the use of horses and hand loading to rubbertired skidders and knuckleboom loaders to recent trials with cable yarding. Cable yarding requires roads 800 to 1000 feet apart, an efficient crew, and a high valued product mix to make the system economical.

STEEP TERRAIN HARVESTING—AN INDUSTRY PERSPECTIVE

John E. Buckhalt

When I looked at the title that Penn Peters assigned to me "Steep Terrain Harvesting - An Industry Perspective" I had to think a moment and to define in my own mind exactly what a perspective connotates. And I quickly realized that a perspective or view is something that is generally seen from a distance. I then assumed that this group could better relate to my presentation if that view was one of close up. So I elected to share with you gentlemen today an experience, if you will, rather than a view. So let's consider this an experience of an industrial operation as it undertook a 30 year quest for successful steep mountain logging in the Blue Ridge Mountains of Virginia.

Perhaps you are asking just what qualifications might I have to speak from an experience standpoint? Before I answer that, let me digress for a moment and relate to you a story I heard of a very successful elderly gentleman who was once asked, "To what did he attribute his fame and fortune?" He replied, "Being able to make the right decisions. "His listener acknowledged this over simplified answer and asked, "But sir, how do you know that your decisions are right when you make them?" The reply was, "Young man, that's when you must rely on experience." The young man, eager to learn of his secret, wanted to know just how can one get this needed experience. The answer from the old gentlemen was, "By making a few bad decisions."

Needless to say, some of our experience was acquired in a similar manner. My company, Owens-Illinois, is presently operating a 650 ton 9 Point pulp and paper mill in Big Island, Virginia on the James River, which is about midway between Lynchburg and Natural Bridge. This mill has had several owners with its genesis back to the 1890's, and has the distinction of being one of the oldest pulp and paper mills in the United States.

In order to keep things in the proper perspective, let me start by giving you a historic review of how we became

involved in steep mountain logging. Prior to 1954, our mill was wooded almost exclusively by rail wood shipped from the Piedmont of Virginia. This hardwood pulpwood was procured from flat to rolling land -- was reasonably straight in form -- had heavy volume per acre -- was easily accessible for stump loading and could be shipped by rail with economical freight rates. An abundant labor supply that was willing to hand load five (5) foot pulpwood completed this almost perfect procurement picture. However, one by one, the advantages of this Piedmont oriented procurement system began to show signs of weakness that effected the overall economics, and as future expansion was planned for Big Island, a major decision was made to phase out the Piedmont oriented procurement system.

Being that Big Island was located in the Blue Ridge Mountains, the time had come to utilize the tremendous volumes of hardwood that were virtually within a stones throw of the mill. This resource was located on the George Washington National Forest and it was on steep mountain land that, heretofore, had not been logged for pulpwood. This change in strategy made economic sense, if it could be done. A few of our foresters of the time believed it could be done and the project had its beginning in 1954, in the form of an unprecedented 10 year sale with the George Washington National Forest. As a note of interest, this transaction with the Forest Service was publicized as the largest government timber sale ever made east of the Mississippi River. Closer examination of the type of topography, stand composition, age distribution, and timber quality revealed some unique characteristics that were to impact our experience with steep mountain logging in the years to follow. So I think perhaps a brief ecological review of the history of these stands would help explain these sivicultural conditions as we found them in 1954, and help set the stage for the remainder of my presentation.

This particular mountainous section of Virginia, prior to the mid 1800's when the narrow gauge railroad loggers appeared, contained a mature, dense, high quality hardwood and pine forest made up principally of American Chestnut, White Oak, Red Oak, Maple, Yellow Poplar, and White Pine. With the cutting philosophy of the railroad logging companies and the use of their cable yarding steam donkey's, virtually every stand that contained high quality sawtimber was logged. In those early days there was very little concern for the surviving residual stands, site damage, or stream pollution. At this point in time, man's logging activity began the specie selection process and mother nature soon joined in with top soil erosion from the steep slopes. While the hollows ended up as catch basins for the rich top soil, the steep slopes

were exposed to all the elements. Wild fires ravaged the areas on a regular basis, and the second growth timber stands that resulted were of inferior quality.

Prior to the end of the 1800's, the remaining Chestnut virgin sawtimber that survived the railroad loggers was now doomed by the Chestnut blight. During this turn of the century, and into the 20's, the National Forest ownership was expanded and for the most part the roughest, steepest, cut over lands were the properties the private sectors sold to the government.

Our area of Virginia fitted the above description. By 1954, the earlier logging damage and the Chestnut blight, had all but been forgotten to most; however, the specie composition with Chestnut Oak and other inferior species predominating on the poor thin mountain soils and the abundance of large stumps which were once majestic American Chestnut and other more valuable species was a grim reminder of the past.

This was the resource we had agreed to utilize by our contractual commitment which took effect in 1954. We knew we had a job to do and a logging job of this magnitude in steep mountain terrain had never been done by our company before. We called upon our experience with our Northern logging operation in Michigan and Wisconsin and decided we would, at least initially, log this ten (10) year sale patterned after our Northern operations. Now this decision was far easier said than accomplished. For we had to: (1) Recruit mountain loggers that were accustomed to the horse and mule logging techniques. (2) Build and equip two (2) man shanties on skids that would permit easy removal from one logging job to another. (3) Provide the loggers with horses, the black smithing, all harnesses and rigging, black powder with splitting wedges, and axes and bow saws. (4) Keep this logging force supplied with groceries on a regular basis, for in most cases these cutting sites were located many miles back into the mountain areas.

Our operation was designed to be a downhill horse logging job with company built roads every 600 feet apart. The wood was initially cut in 7 1/2' lengths for pulpwood and log lengths for sawtimber and hand piled along the roadsides for subsequent company crane loading and hauling. The loggers were paid on a flat piece rate basis. Within a short time the company hauling gave way to producer owned and operated Bob Tailed trucks. The transition to Tandem trucks soon followed. Horse skidding required and demanded a personal commitment from the loggers and small crawler tractors began to replace

the horses. Most hand loading continued into the 60's, despite the introduction of the big stick loader, or the home made jammer. We introduced the first cable rehaul system in 1961. This was the big stick loader with rehaul consisting of a rear mounted boom and rehaul wench. When this unit became operational we had our first uphill mountain logging system. However, the idea did not catch on and we soon returned to the conventional downhill logging.

The rubber tire skidder made its debut in our operation in 1962, in the form of a company purchased Timberjack 215. There were many skeptics who believed that the skidder would never replace the horse and tractor, but time proved that this single piece of equipment had a great impact on steep mountain logging. Now both uphill and downhill skidding over extended distances could be accomplished.

In 1963, we introduced the first knuckleboom loader and soon made hand loaded wood something of the past. While all of these innovations were helping to increase productivity and permit the contractor to cope with the ever increasing cost of living and changing work attitudes of the woods laborer, we were still experiencing problems in keeping good contractors. As we closed out the government sale in 1965, we embarked on the second phase of our experience in steep mountain logging. Over the next 15 years we acquired extensive ownership of mountain timberlands and began to put into play the road building and logging techniques that we had used on the government sale. By this time we were more dependent on our company mechanized crews than we desired, but with a high cost of insurance and equipment, there were few new comers to the trade. The company operations were designed around rubber tired skidders, knuckleboom loaders, and tri-axle diesel haul trucks and we had just about turned over every rock in search of ways to improve productivity, maximize the use of our resource and keep our costs in line.

In the early 70's, we found one more rock to turnover and that was the concept of cable logging the steep slopes. Interest was raised and several cable systems where explored. The systems used in our Western United States were large, expensive, and slow and the European cable systems were not much better. In 1974, we began our cable logging on-the-job experience by trying the Urus cable yarder. If we had taken time to determine the definition of its name we may have avoided some real disappointments. Webster defined Urus "As a wild, large, horned ox that is now extinct." Our Operations Manager remembered the occasion well. And I quote, "The crew cowardly gathered around the machine the first day while setting it up and the next four days they lugged a 40 lb. ball

up and down the slopes, but moved very little wood." The conclusions that were arrived at following this experimentation was that cable logging could not compete economically with conventional systems due to the cost, size and slowness. At that time we lacked the immediate need, technology and time to pursue cable logging further and the idea was shelved.

Throughout the 70's, following our brief disappointing exposure to cable logging, we continued with our conventional logging and extensive road building programs. In 1977, the results of our continuous forest inventory presented some startling figures for us to digest. On our fee timberlands, above 3,000 feet elevation, we had average volumes of over 30 cords per acre. While on stands below 2,000 feet our average acre contained only 17 cords. Our planning now responded to our needs and we began moving up the slopes with roads and skid trails. However, a new force to reckon with soon emerged and that was the wrath from the public and environmentalists who were responding to long-range visible scarring of steep slopes caused by conventional logging methods. The steeper the areas encountered the more problems we found with road building, safety, aesthetics and costs. We seemed to lack the motivational influences back in the early 70's, when we tried the Urus, but now we realized that we had both internal and external motivations that justified another look at cable yarding.

As we moved out of the 70's and into the 80's, we were convinced that we needed to find a cable system that would enable a contractor to clearcut as well as selectively harvest at a cost equal to that for conventional logging.

In 1981, after recalling our 1974 experience with the Urus and after having spent considerable time visting other cable operations, we made a commitment and purchased a Koller K-300 yarder. Our three (3) year experience with this cable yarder on our timberlands as well as U.S.F.S. sales has convinced us of the following:

(1) ROADS - Steep mountain cable logging requires a uniquely different road design than industry or the U.S.F.S. has historically used to log the mountainous areas. In the past, most horse, tractor, and skidder operations were designed for downhill logging with many of the landings built on flats or in bottoms, thus acting as a hub of a wheel with the skid trails all leading downhill to the central hub. This system worked well for horses, tractors and rubber tired skidders, but with cable yarding the need for specially designed roads are vital. Where once it was a common practice

to build roads 600 feet apart on the side slope, the design now calls for roads up to 800 to 1000 feet apart. Due to the extended reach of the cable system, yarding and loading sites are no longer needed in flat or bottom areas, but should be laid out with particular concern to the topography, existing intermediate support trees, tail block trees, deflection, and angle of pull. Much of this technology was and is difficult for the average logger to fully understand and to use to his advantage without proper training. Yet the new demands of steep mountain logging have made it a vital part of the economics of todays cable logging.

The yarding sites located on existing roads have for the most part proved to be too small to properly accommodate the yarder location, wood drop zones and the truck loading areas. In some cases the back slopes of the existing roads could be excavated, but by the very nature of the general conditions of the steep mountain terrain the expense necessary to widen the roads are often too costly. When the initial roads were laid out and built little consideration was given to the many factors which can make or break a cable operation.

(2) MANPOWER - Cable logging requires a high level of personal energy consumption and hence, is a young man's game. The key to productivity is the number of turns per hour and volume per turn. The speed of the ground hooking crews play a vital role highlighting the need for good team work and good radio communications with the yarder. We also found that cross training and job switching helps reduce personal fatique and keeps team morale high.

(3) CLEARCUT VS. SELECTIVE CUT - Contrary to common belief, a selective cut can be made with a cable operation without sacrificing productivity if the quality of the product is high enough. We found that productivity in the summer suffers when a clearcut is made due to the lack of shade and the resulting personal fatigue as contrasted to a selective cut that offers shade to the cutters.

(4) ECONOMIC FACTORS - It must be remembered that each wood using industrial operation is determined to supply their raw material needs from the most ecnomical source available. And in some instances, this source will be government sales involving steep mountain logging, if the cost to product value ratio is reasonable. Here lies the crust of the entire problem concerning the economics of cable logging steep mountain terrain.

We find that todays heterogeneous stands of mountain hardwoods and pine contain uneven aged stands with all degrees

of value distribution as well as size class distribution. Much of this steep timberland, almost inaccessible in past years from a conventional logging standpoint, was subjected to the periodic fire damage prior to government ownership that I described earlier in this presentation, resulting in fire damaged sawtimber.

Our technological advances in cable yarders have provided us with some well engineered systems, but we unfortunately have not found the perfect combination of machinery that is adaptable to large mature sawtimber, as well as small diameter pulpwood, and is priced low enough for the small producer. In most cases we find ourselves gearing up to handle the larger more valuable stands of sawtimber, and hope that the high cost of pulling small diameter low value pulpwood will be offset by the sawtimber. In other words, we are by necessity attempting to subsidize our low grade production with high value production. To the extent this can be done -- all is fine; however, in the real world we know that our steep mountain stands do not contain enough high value sawtimber to write off the high production costs of the low grade products.

Regardless of the yarder employed, the machine cannot tell the difference between high grade/high value, and low grade/low value logs being brought into the landing on each turn. Our experience with the Koller yarder has proven its usefulness on company operated pulpwood harvesting jobs on steep mountain sites. However, unit costs have been considerably higher than conventional logging due primarily to lower production rates, and the absence of qualified independent contractors willing to make the transition from conventional to cable logging. Our hope of seeing this type of system owned and operated by an independent contractor has yet to become a reality. But, with the continuing improvement in our economy we are still optimistic.

In summary, it is interesting to note that the demise of the cable logging systems, that were common in the Eastern United States from 1900-1930, were directly tied to the removal of the old growth high valued timber that made the systems economical. I believe that the future of the modern day producer owned cable logging system in our area will also be closely tied to the availability of a higher valued product mix in order to make the system economical. In the absence of this high value product mix on federal lands where in some cases conventional logging is prohibited by policy, then the land manager will have to accept the fact that the stand cannot be logged until such time as supply and demand mandates a higher unit stumpage value. On private lands the independent, if left to his own choice, will probably continue

to utilize the conventional logging methods on mountain land and will bypass the very steep slopes, until such time as the economics change.

We in industry feel the obligation to help the independent contractor find the proper system that meets all of our needs in our quest for solving the problems of steep mountain logging. We salute you gentlemen here today who are in applied logging research and we appreciate the opportunity to be here and to share our experiences with you.

MAP - A MAPPING AND ANALYSIS PROGRAM
FOR HARVEST PLANNING

by

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ABSTRACT

The Northeastern Forest Experiment Station and the Department of Civil Engineering at West Virginia University are cooperating in the development of a Mapping and Analysis Program, to be named MAP. The goal of this computer software package is to significantly improve the planning and harvest efficiency of small to moderately sized harvest units located in mountainous terrain. The intention is to develop an interactive user friendly system to be implemented on the Hewlett-Packard 9845 computer system. Data is input to MAP from coding forms which are completed in the field as a result of a simplified form of survey information. The field survey consists of a systematic gathering of a series of bearing, distance, and percent slope measurements using a survey compass, tape, and clinometer. All data is gathered during survey traverses which connect a consecutive series of stations. The purpose of the traverses are to gather map information for the purpose of defining the topography, enclosing areas, defining linear features, and locating points of interest.

A typical MAP application consists of a planned series of traverses for the purpose of capturing any data that might be depicted on a standard paper map or drawing of a harvest unit. The advantage in using MAP is the ability to input original harvest unit survey data obtained using a simplified survey procedure. As a result, the harvest planner is no longer restricted to inappropriate map scales and insufficient accuracy. He can select his own map scale and include only that data required for his analysis. Following input of the raw field survey data, all computations are handled automatically in software yielding a data base from which a variety of products can be obtained. Examples of final output include maps of the cutting unit area with topographic contours, harvest unit perimeter length and area, and ground profiles along cableways and skid roads. In addition, horizontal and slope distances from landings to potential tailholds, or from landings along potential skid roads can be obtained as an integral part of a payload analysis for corridors of interest. Although the inner workings of the software package appear to be quite complex, this complexity is not seen by the user in the user friendly interactive environment.

MAP—A *M*APPING AND *A*NALYSIS *P*ROGRAM FOR HARVEST PLANNING

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INTRODUCTION

The Northeastern Forest Experiment Station and the Department of Civil Engineering at West Virginia University are cooperating in the development of a Mapping and Analysis Program, to be named MAP. The goal of this computer software package is to significantly improve the planning and harvest efficiency of small to moderately sized harvest units located in mountainous terrain. The software package is to be implemented on the Experiment Station's Hewlett-Packard 9845 computer system.

The basic philosophy behind the development of the subject software package is to produce a user friendly system that will not only be easy to operate by harvest planners, with few computer skills, but will utilize input data that is relatively simple to acquire. The basis of the software system is to be a Geographic Information System (GIS) as described in (1). The most important component is a Triangulated Irregular Network (TIN) digital terrain model. The TIN is to be generated automatically using many of the software features described in (1). A major difference will be the use of field survey data instead of existing contour maps.

Several terrain modeling systems are available to the Forest Service for planning and management purposes. Examples are the TOPAS (Topographic Analysis System), DTIS (Digital Terrain Information System), MOSAIC (Method of Scenic Alternative Impacts by Computer) (2); and LANDFORM (Land Analysis and Display for Mining) (3). Each of these systems utilize digital terrain models in the form of a regular or irregular network of X-Y coordinates with assigned elevations. Although based on an irregular network terrain model, the MAP system is intended to be more comprehensive in its analysis capability. Unlike other modeling systems, MAP will not be limited in the type of data that can be input. In addition to terrain information, any spatial, linear or point data can be input using a simplified surveying technique. The uniqueness of the MAP system is the use of simple field survey procedures requiring only a

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compass, clinometer and tape. In spite of simplicity, the analysis capability of the system has the potential to be broadly applied in harvest planning. The method of MAP data base construction and its application are discussed in the following sections.

DATA BASE CONSTRUCTION

Data is input to MAP from field coding forms that are completed during a comprehensive survey of the harvest unit. The MAP data input software is designed to utilize a simplified form of survey information based on use of a survey compass, tape, and clinometer. The entire field survey of the unit relies on a systematic gathering of a series of bearing, distance, and percent slope measurements. These series of measurements are called a "traverse". While conducting a traverse the surveyor is provided with options of gathering additional information relating to area attributes, line or boundary types, and point or station classifications. Area attributes might denote the interior of the harvest unit as differentiated from areas external to the harvest unit; or, area attributes might be assigned according to forest types or environmentally sensitive areas within the harvest unit. Line or boundary information can be assigned along a traverse to identify linear features within the data base such as skid trails or area classification boundaries. The remaining possibility is a need to identify points or stations such as potential landings and tailholds. The following paragraphs illustrate the structure of this data base and its construction methodology.

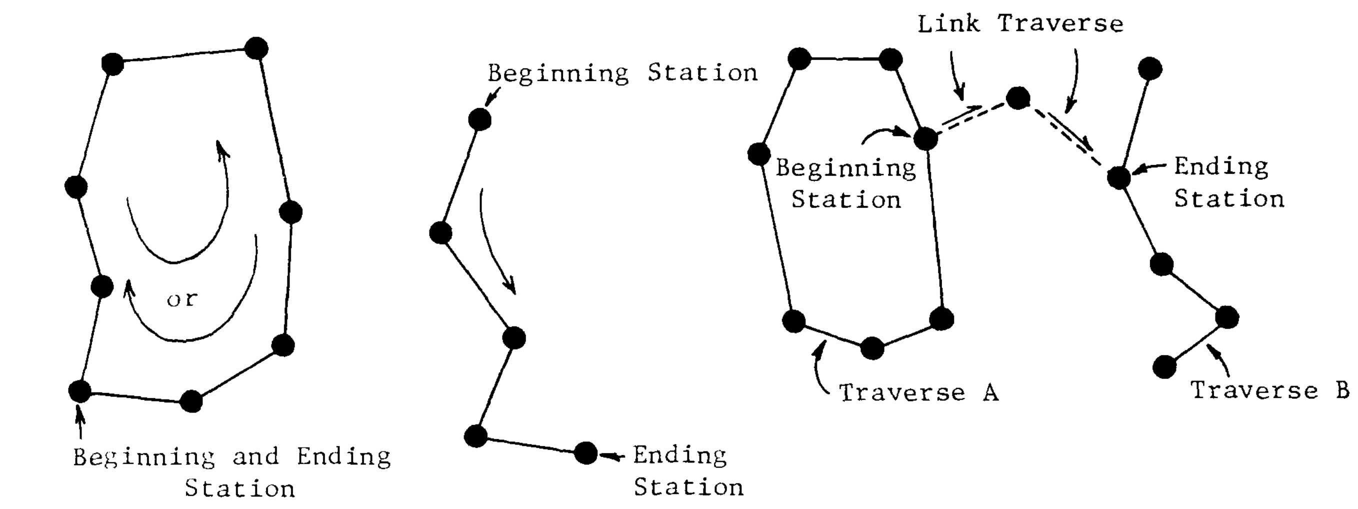
Traverses

The MAP data base structure originates as a systematic survey of the harvest unit. Most basically, all map-type data can be classified as area, line, or point data. A series of planned survey traverses can provide each of these data types, as needed, to fully map the area of interest. The survey traverse is defined as a series of bearing, distance, and percent slope measurements connecting a beginning station with an ending station. The traverse can be applied in any one of several different ways as illustrated in Figure 1.

The traverse must begin at a station and proceed to the next station in the traverse by specification of a bearing, distance, and percent slope. As illustrated in Figure 2, the bearing can be given as azimuth (0-360^{o} clockwise from magnetic north) or as bearing from the north-south meridian (0-90^{o}) in one of the four quadrants. Distance is measured as slope distance along the bearing to the next station. Slope is specified as a positive or negative value in percent, as appropriate. The stations are connected by "links" and the links are joined end-to-end in a sequential string until the traverse closes on itself, or is ended. Each station is identified by a unique number during the survey traverse. Link numbers are assigned automatically during computer processing of the data.

Regardless of the intended function of the traverse, line and point attribute data can be assigned to each link and station, respectively. The rules governing the completion of a traverse are minimal and can be listed as follows:

1. A traverse can be closed, but only to its beginning station.



a) Closed Traverse   b) Open Traverse   c) Link Traverse

Figure 1. Examples of Three Possible Traverse Types.

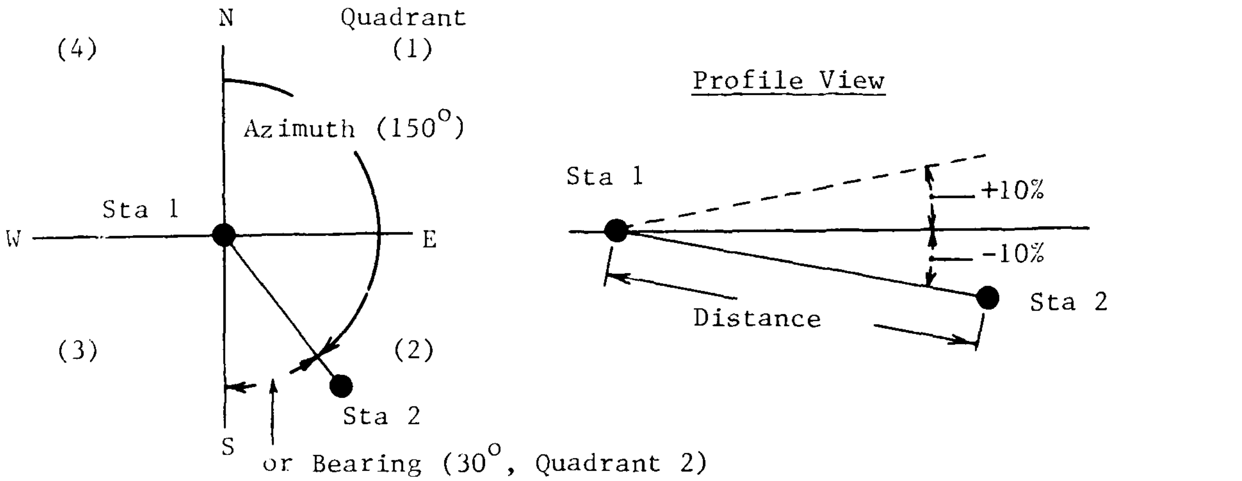


Figure 2. Example of Station to Station Measures of Bearing, Distance, and Slope.

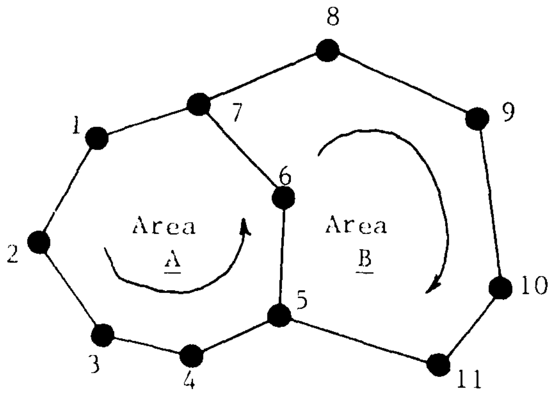


Figure 3. Assignment of Area Attributes in Closed Traverses

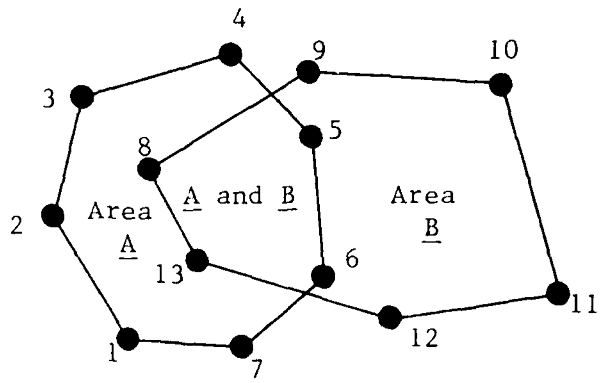


Figure 4. Illustration of Overlapping Closed Traverses

2. .. traverse can share stations and links with other traverses as long as the original station numbers remain unique and unchanged.
3. The numbering of new stations must be sequential.
4. A traverse must consist of a continuous chain of links resulting from the bearing, distance and slope measurements taken from one station to the next.
5. A traverse cannot cross itself or contain a repeated station number. (Exception: the beginning and ending station number must be identical in a closed traverse).
6. To maintain data base connectivity, each individual traverse must share at least one station with another traverse within the data base.

As shown in Figure 1, traverses generally perform one of three functions. They enclose areas, represent linear features, or serve to connect two existing traverses. Also, any of the three types classified by Figure 1 can be used to locate point information. Each of these traverse types are discussed in more detail below.

Closed Traverses

A closed traverse contains a minimum of three links (3 stations) and must close to the beginning station without crossing itself. As shown in Figure 1 the traverse can be closed in a clockwise or counter clockwise direction. In general, the purpose of a closed traverse is to bound an area that has unique attributes. Therefore, an area attribute assignment is often made with respect to each closed traverse as shown in Figure 3. Since each traverse closes in a clockwise or counter clockwise direction, the inside and outside areas of the traverse are identified and the area attribute assignment can be associated with the enclosed area.

Each link and/or station around the traverse can be assigned attributes. Logically, links are assigned line or boundary attributes, and stations are assigned node or point attributes. Stations are assigned unique identification numbers, in sequential ascending order, at the time of the survey. No link identification numbers are assigned since each link can be identified by its beginning and ending station number. The attribute codes, if assigned, are in addition to the identification numbers.

Closed traverses can adjoin one another as shown in Figure 3 or they may overlap one another as shown in Figure 4. Area attribute assignments are made separately for each closed traverse. Overlapping closed traverses share a portion of the same area, and therefore, that shared area has more than one attribute assigned to it. Areas of shared attributes are assigned automatically by the computer software.

A specialized subset of closed traverses is defined to permit acquisition of terrain data. This latter type of traverse is called a DTM (Digital Terrain Model) traverse. The sole purpose of the DTM traverse is to create a relatively uniform array of coordinate-elevation points that serve as the foundation of the MAP data base structure. As illustrated in Figure 5, the traverses are of an approximate elongated rectangular form. They are used in multiples, aligned to a common direction, as required to fully cover the map area for which the total data base is to be constructed. Each elongated rectangle is closed to its beginning station such that station spacings, Δx and Δy, are on the average, approximately equal. Ideally, a rectangular

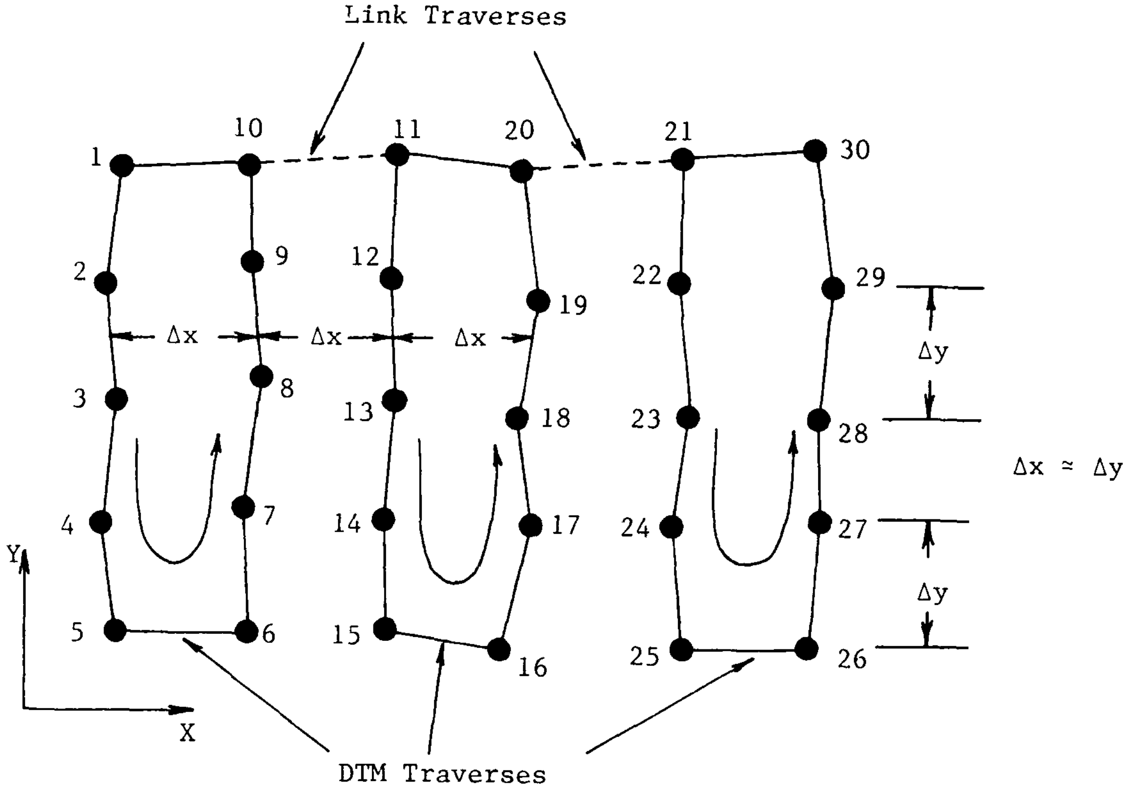
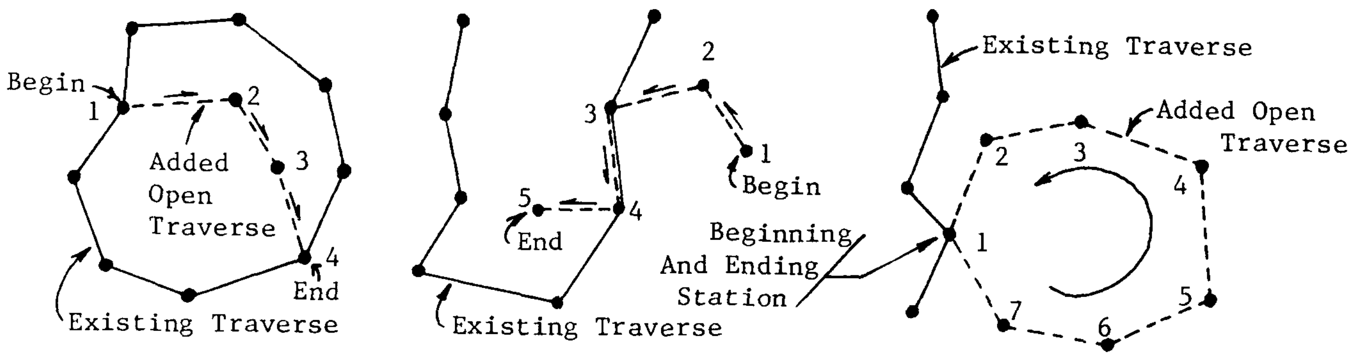


Figure 5. Configuration and Alignment of Digital Terrain Model Traverses.



a) Beginning and Ending on Another Traverse

b) Partial Sharing of Links

c) A "closed" Open Traverse Sharing A Common Station

Figure 6. Examples of Possible Open Traverse Use.

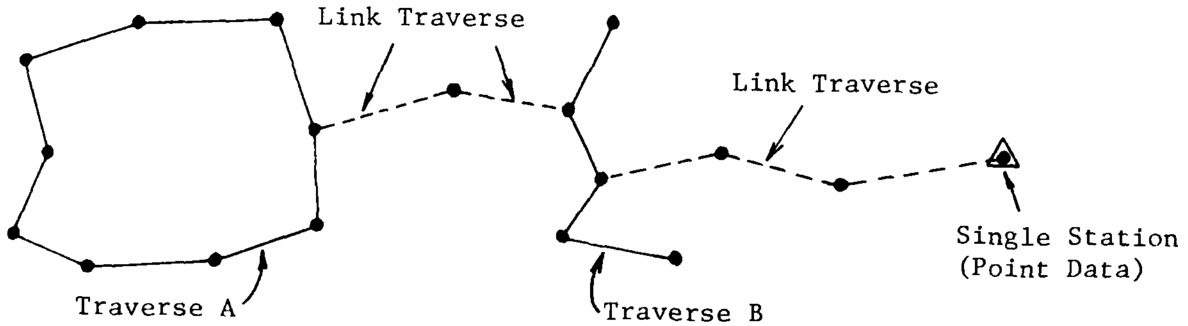


Figure 7. Examples of Link Traverse Application.

grid of stations spaced equally in Δx and Δy would result. However, the survey technique used does not permit this level of control. Since a triangulated irregular network (TIN) is used to interconnect the coordinate-elevation points, perfect control of Δx and Δy is not required. A DTM traverse is intended solely to construct the digital terrain model, and therefore, is not assigned attributes. Other than this limitation, all other rules regarding closed traverses apply.

Open Traverses

Closed traverses are for the purpose of enclosing areas or establishing the digital terrain model. Although each link in a closed traverse can be assigned attributes, line information is intended to be obtained by use of an open traverse (Figure 1). As befits its name, an open traverse does not enclose an area. It is a series of bearing, distance and slope measurements connecting a sequential set of stations along a linear feature. The traverse cannot cross itself, but may cross other traverses. Each open traverse can be assigned a line attribute common to all links in that traverse or attributes can be assigned to the links individually. The stations in the traverse can be assigned point attributes as before. The beginning and ending stations in an open traverse do not have to be common to another traverse as long as one of remaining stations is a common station. But it is permissible to begin and end an open traverse at stations common to another traverse (as shown in Figure 6). It may even begin and end at the same station. In this latter case the open traverse becomes a closed traverse, but without specification of a closure direction or assignment of an area attribute.

Link Traverses

Link traverses are a special application of open traverses for the purpose of connectivity and location of point data. It is not always convenient for a traverse to share one or more of its stations with another traverse to provide connectivity. In lieu of this direct connectivity, two traverses may be indirectly connected by a third open traverse, called a link traverse (see Figure 7). A link traverse is an open traverse used under more constrained conditions. Specifically, the beginning station of the link traverse is shared with one of the two traverses, and the ending station is shared with the remaining traverse. As shown in Figure 7, the link traverse can also be used to link a single free-standing station, of important attribute, to one of the traverses within the data base. Examples of single station data include landings, tailholds and bench marks. Although the link traverse application can include link attribute and point attribute assignments, as with any open traverse, there is little point in using the "link" label unless the traverse is primarily serving a "linking" function. If the traverse is performing multiple functions, then it would be more aptly called an open traverse.

Data Base Example

To illustrate the application of the proposed MAP software system, an example is presented. As shown in Figure 9, the field data acquisition format is relatively simple due to a common format for all traverses, regardless of their purpose. The data acquisition form is divided into two parts. The left side of the form records information pertaining to stations, while the right side records link information. The lines are staggered to emphasize

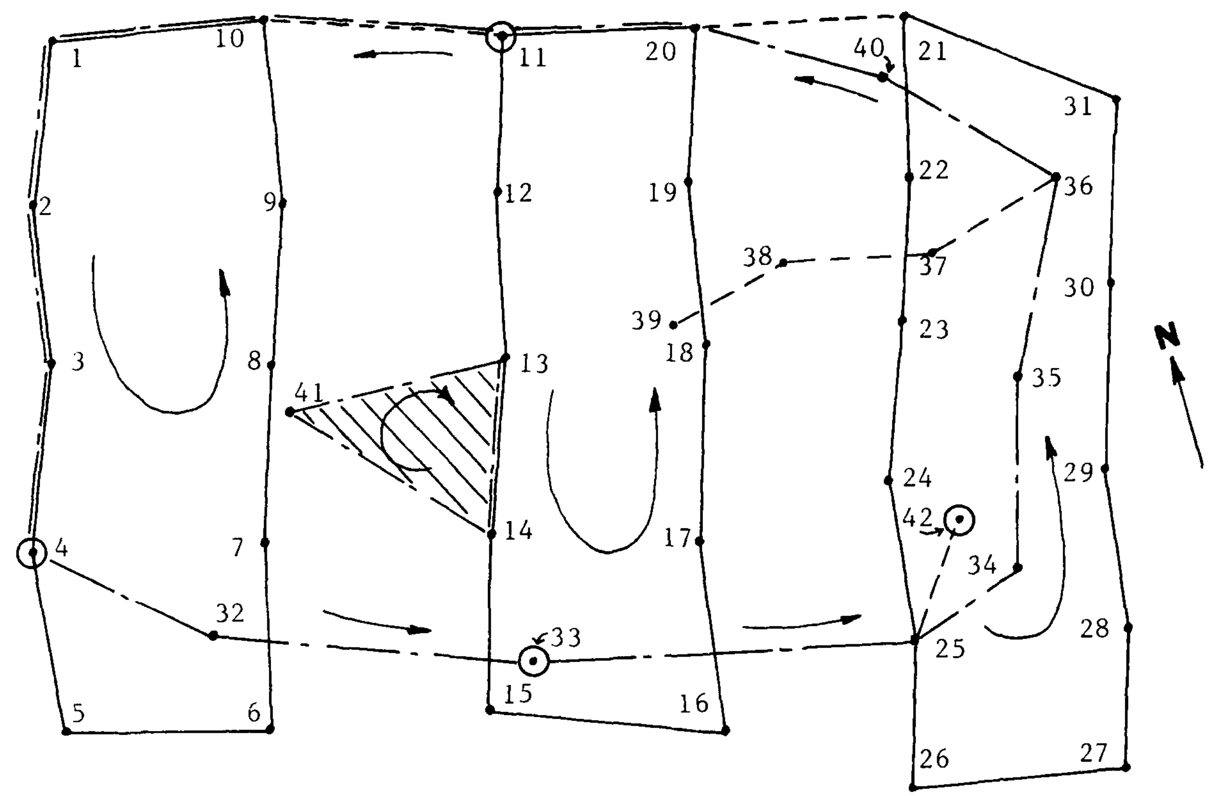


Figure 8. Example Harvest Unit Data Base

Triangulated Irregular Network (TIN) DTM

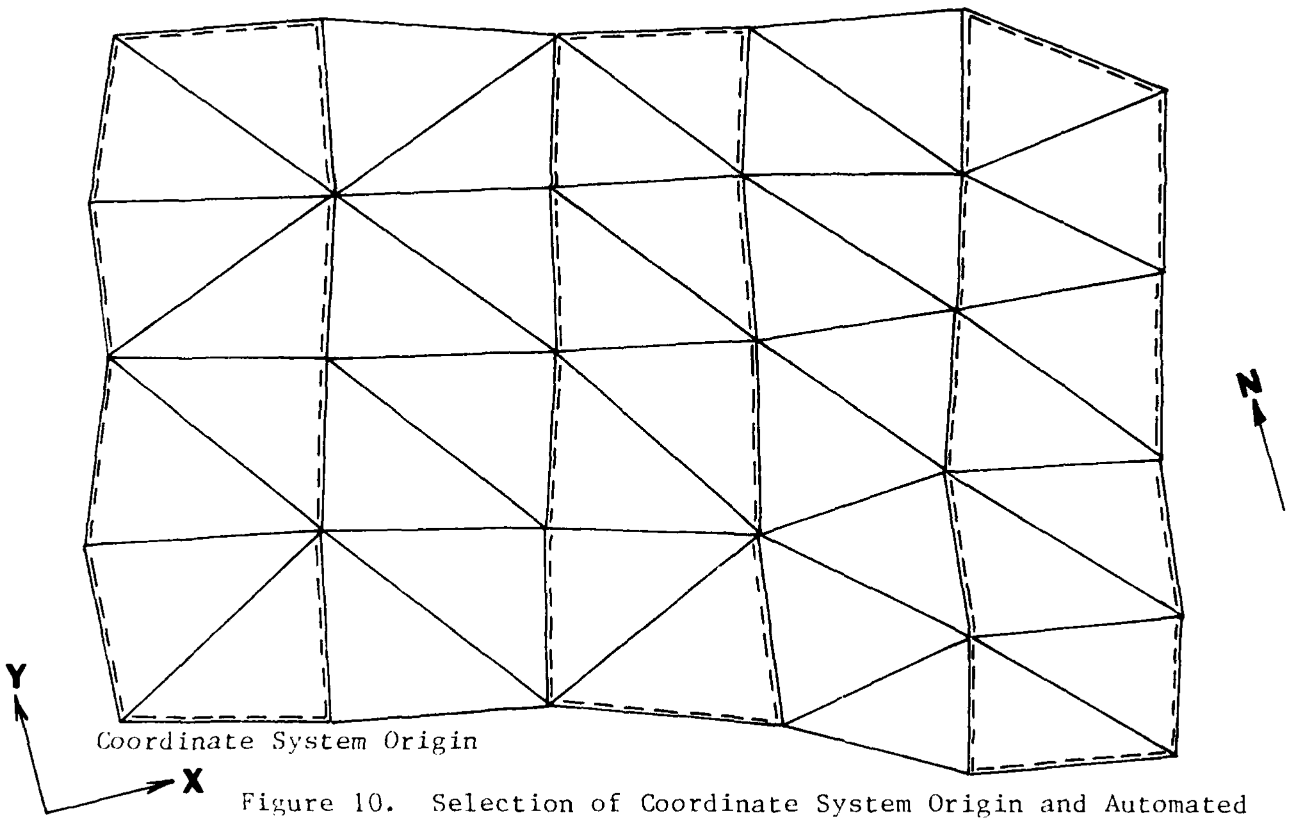


Figure 10. Selection of Coordinate System Origin and Automated Triangulation of Terrain Survey Stations.

the serial station-link-station order of data acquisition.

Since a traverse must begin or end at a station, the station line begins with the traverse beginning or ending code, B or E. The next entry on the same line labels the traverse type as DTM, closed, open or link. Following the traverse type is the station number. Although the station numbers need not be sequential along a given traverse, they must be sequentially assigned to each new station without skipping numbers. Station attribute codes are entered next, followed by the area attribute. The area attribute is required at the first station of a closed traverse. The link line is between and to the right of sequential station lines, since this information must be entered in traversing from one station to the next. The quadrant number is entered only if bearings are measured with respect to the north-south meridian. Following the bearing, distance and then slope are entered. Lastly, link attributes are entered. This process is continued until the traverse closes or is terminated at the ending station.

To illustrate the use of the data acquisition form, the example harvest unit survey shown in Figure 8 is coded in Figure 9. To properly survey a forest harvest unit, the total data base area must be bounded so that the digital terrain model (DTM) can be constructed covering this area. The DTM traverses are required to fully cover the study area so that all other traverses lie on or within the outer limits of the terrain model. The DTM traverses are completed first. As shown in Figure 8, the first DTM traverse is completed using 10 stations. Table 1 summarizes the station sequences for each traverse. In Figure 9 it will be noted that a possible tailhold location is coded at station 4 by the attribute number 3 (line 4S). Table 2 identifies the attributes assigned in this example. The first DTM traverse is closed back to station 1 using the end code, E (line 11S). The second traverse is a link traverse for the purpose of linking the first DTM traverse to the second. This link traverse has one link from station 10 to station 11. Station 11 initiates the second DTM traverse (line 14S) which utilizes stations 11 through 20. It will be noted that station 11 is also a landing site, coded with the appropriate attribute in the previous link traverse. This latter attribute code could have been assigned during the second DTM traverse. Station or link attributes can be assigned at any point where those elements are encountered in the coding process.

The second DTM traverse illustrates the ability to nest one traverse within another. That is, a given traverse can be halted at some intermediate point and a new traverse begun. On line 18S a nested traverse is initiated at station 14. The second DTM traverse within which this new traverse is nested is temporarily halted until the new traverse is completed. This concept is directly analogous to nesting do-loops in a computer program. The inner traverse is a three link closed traverse for the purpose of inclosing an environmentally sensitive area. Link 13-14 (line 20L) of the inner traverse is shared with link 13-14 (line 16L) of the outer DTM traverse. Since the bearing information has already been provided, line 20L is left blank except for any additional attribute codes. Line 21S closes the inner traverse and control returns to the outer DTM traverse. The DTM traverse is closed on line 28S at station 11. The third DTM traverse is coded in the same manner as the first two.

The harvest unit boundary traverse begins on line 43S, station 1. The first three links repeat links already established, and therefore, directional

Figure 9. Field Data Form Format Using Examp. Harvest Unit in Figure 8.

	Begin or End Traverse	Traverse Type (See Table 1)	Station Number	Station Attribute Codes (See Table 2)	Area Attribute
1S	B	DTM	1		
2S			2		
3S			3		
4S			4	3	
5S			5		
6S			6		
7S			7		
8S			8		
9S			9		
10S			10		
11S	E	DTM	1		
12S	B	LINK	10		
13S	E	LINK	11	2	
14S	B	DTM	11		
15S			12		
16S			13		
17S			14		
18S	B	CLOSE	14		2
19S			41		
20S			13		
21S	E	CLOSE	14		
22S			15		
23S			16		
24S			17		
25S			18		
26S			19		
27S			20		
28S	E	DTM	11		

	Bearing: Quadrant Number	Bearing: Degrees	Bearing: Minutes	Distance, ft	Slope, ±%	Link Attribute Codes (See Table 2)
1L	2	29	20	80	-10	
2L	2	20	11	75	-12	
3L	2	35	05	110	-8	
4L	2	10	18	100	-6	
5L	1	02	28	112	1	
6L		31	46	118	6	
7L		40	22	91	8	
8L		36	18	85	12	
9L		20	32	82	10	
10L	2	28	12	122	-1	
11L						
12L	1	02	52	116	1	
13L	2	15	32	101	-10	
14L	2	10	16	105	-11	
15L	2	01	35	106	-9	
16L	2	15	26	112	-8	
17L						
18L	3	10	36	130	6	4
19L		96	10	98	2	4
20L						4
21L	2	01	16	89	-8	
22L	1	15	41	122	-1	
23L		25	06	102	6	
24L		35	12	108	8	
25L		21	25	82	10	
26L		28	13	75	12	
27L	3	02	31	92	-1	

Figure 9. cont'd

	Begin or End Traverse	Traverse Type (See Table 1)	Station Number	Station Attribute Codes (See Table 2)	Area Attribute
29S	B	LINK	20		
30S	E	LINK	21		
31S	B	DTM	21		
32S			22		
33S			23		
34S			24		
35S			25		
36S			26		
37S			27		
38S			28		
39S			29		
40S			30		
41S			31		
42S	E	DTM	21		
43S	B	CLOSE	1		1
44S			2		
45S			3		
46S			4		
47S			32		
48S			33	3	
49S			25		
50S	B	LINK	25		
51S	E	LINK	42	3	
52S			34		
53S			35		
54S			36		
55S	B	OPEN	36		
56S			37		

	Quadrant Number	Bearing Degrees	Bearing Minutes	Distance, ft	Slope, ±%	Link Attribute Codes (See Table 2)
28L		100	22	98	-1	
29L						
30L		195	16	92	-10	
31L		201	37	72	-8	
32L		192	46	96	-11	
33L		212	21	98	-10	
34L		223	41	82	-9	
35L		101	08	101	-2	
36L		34	11	62	9	
37L		24	16	82	9	
38L		38	44	97	11	
39L		45	19	105	12	
40L		310	48	127	5	
41L						
42L						1
43L						1
44L						1
45L		162	51	101	-9	1
46L		172	09	152	-4	
47L		135	27	192	-2	1
48L						
49L		62	21	51	6	
50L		75	16	48	5	1
51L		106	24	105	7	1
52L		34	32	101	10	1
53L						
54L		210	16	58	-5	2
55L		281	32	68	1	2

Figure 9. cont'd

	Begin or End Traverse	Traverse Type (See Table 1)	Station Number	Station Attribute Codes (See Table 2)	Area Attribute
57S			38		
58S	E	OPEN	39		
59S			40		
60S			20		
61S			11		
62S			10		
63S	E	CLOSE	1		
64S					
65S					
66S					
67S					
68S					
69S					
70S					
71S					
72S					
73S					
74S					
75S					
76S					
77S					
78S					
79S					
80S					
81S					
82S					
83S					
84S					

	Bearing: Quadrant Number	Bearing: Degrees	Bearing: Minutes	Distance, ft	Slope, ± %	Link Attribute Codes (See Table 2)
56L	2	35	11	46	-2	2
57L	3	20	40	116	5	1
58L	3	01	28	100	4	1
59L						1
60L						1
61L						1
62L						
63L						
64L						
65L						
66L						
67L						
68L						
69L						
70L						
71L						
72L						
73L						
74L						
75L						
76L						
77L						
78L						
79L						
80L						
81L						
82L						

Table 1. Traverse Station Survey Sequence (Figure 9. Example).

traverse	type	Station Sequence	Traverse Purpose
1	DTM	1-2-3-4-5-6-7-8-9-10-1	Digital Terrain Model
2	Link	10-11	Link two DTM's
3	DTM	11-12-13-14-15-16 17-18-19-20-11	Digital Terrain Model
4	Link	20-21	Link Two DTM's
5	DTM	21-22-23-24-25-26-27-28-29-30-31-21	Digital Terrain Model
6	Link	25-30	Link Harvest Boundary to Tailhold
7	Open	36-37-38-39	Locate skid road
8	Closed	13-14-41-13	Inclose Environmentally Sensitive Area

Table 2. Example Station, Link, and Area Attribute Codes

Point	Line	Area
1 - Bench Mark	1 - Harvest Unit Boundary	1 - Harvest Unit
2 - Landing	2 - Skid Road	2 - Environmentally Sensitive Area
3 - Tailhold	3 - Power line	3 - Rock Outcrop
	4 - Boundary of Environmentally Sensitive Area	4 - Swamp
	5 - Rock Outcrop Boundary	

information is not supplied in lines 42L, 43L, and 44L. Note, however, that new link attribute information is added denoting the boundary characteristics. Station 33 on the harvest boundary is a potential tailhold, requiring the appropriate attribute code on line 48S. Continuing around the boundary traverse, a nested traverse is encountered at station 25, line 50. This latter nested traverse is a link traverse for the purpose of locating the tailhold at station 42. After returning to the boundary traverse, another nested traverse is encountered at station 36 (line 55S). This open traverse locates a skid road and requires 4 links. The boundary traverse ultimately closes back to station 1 using three links already identified (lines 59L, 60L and 61L). This completes the example as coded herein. It should be understood that the data illustrated in Figure 8 could be coded in many different ways. Another example might not include nested traverses. The traverses could be coded sequentially. The provision for nested traverses is for the surveyor's convenience, allowing the temporary interruption of a traverse in progress to include adjacent data.

COMPUTER PROCESSING

The MAP program is being implemented on the Hewlett-Packard 9845 computer system, using the HP Basic language. Since the 9845 is a dedicated stand-alone system, it can conveniently be used in the interactive mode. The MAP software is to be interactive, with graphics products being available at the intermediate steps.

Following completion of the field survey, the data forms (Figure 9) will be returned to the computer site for data entry. The computer operator first builds a data file that is very similar to the format of the field data form. The information will be entered in the same sequence from beginning to end using the computer's key board.

After the input data file is built, the MAP program is initiated and it reads the input data file, producing internal files of nodes and connecting links for all of the traverses. Attribute files are also maintained in a manner that connects them with the appropriate components. The coordinate system origin is automatically selected in the lower southwest corner of the data base so that all data base coordinates are positive numbers (see Figure 10). Since the digital terrain model (DTM) must bound the data base, the DTM traverses are used to establish the origin and the maximum coordinate limits. A provision will be made to allow optional manual selection of the origin.

Processing of the input data begins with the conversion of the bearing, distance and slope format of the DTM traverses to a X-Y-Z coordinate format, with Z being estimated elevation above sea level. The Z datum is established by entering an elevation estimate for one of the DTM traverse stations. Since the DTM traverses are closed traverses, survey error corrections are accomplished first for each traverse. If no bench mark station is specified within one of the DTM traverses, the first station in the first traverse is assumed to be the bench mark and all error corrections are made with respect to this station. The remaining DTM traverses are closure corrected and the station coordinates established with respect to the first traverse.

A triangulated irregular network (TIN) terrain model is created automatically in software as shown in Figure 10. The triangular elements simulate

the topography of the harvest unit as a surface of triangular facets, as illustrated by the perspective view example shown in Figure 11. The terrain model contains the majority of the basic information needed to feed logging analysis routines. The remaining traverses define boundaries, linear features, and point information pertaining to the proposed harvest unit and its logging system design. Each traverse is processed in turn by transformation to the rectangular X-Y-Z coordinate system of the digital terrain model. At completion, all stations contained within the data base are referenced to the same coordinate system such that the various traverses can be treated as overlays, one on top of another. This commonality permits computations of many map measures of interest to the harvest planner. The following section discusses some of the possible applications of MAP.

APPLICATION TO LOGGING SYSTEM ANALYSIS

The MAP input data processing routines convert all traverses to a common rectangular coordinate system. The resulting common data base then is available for analysis computations. The computations can produce area, length, and slope measures which are intermediate to more complex application analyses, or can be produced as final output. Examples of final output quantities include:

1. Harvest unit perimeter length,
2. Harvest unit area,
3. Horizontal and slope distances from landings to potential tailholds, or from landings along potential skid roads,
4. Ground profiles along cableways and skid roads,
5. List of elevation data by profile and station,
6. Maps of the cutting unit area with contours,
7. and payload analysis for corridors of interest.

CONSIDERATION FOR USERS

The proposed mapping and analysis methodology should provide the logging research and applied industry with a much needed harvest planning tool. The MAP mapping and analysis system requires simple input and should be quite easy to execute. Although the inner workings of the software package appear to be quite complex, this complexity is not seen by the user and he need not be concerned with anything other than entering data and receiving output. The output in the form of unit maps, although simple, would provide most of the terrain and other pertinent information required for most harvest planning.

In order to describe the detail inner workings of the MAP software package, the discussion within this paper may appear cumbersome and complicated. This latter problem is unavoidable in order to discuss the basic model structure and execution. The actual use of the program will be much simpler and more extensively documented. We plan to have the package done and available within 1 year of this paper. Although it is not envisioned that a program such as MAP would provide all the answers to harvest planners, it should provide a simple, inexpensive harvest planning tool. This tool will hopefully result in better decisions being made.

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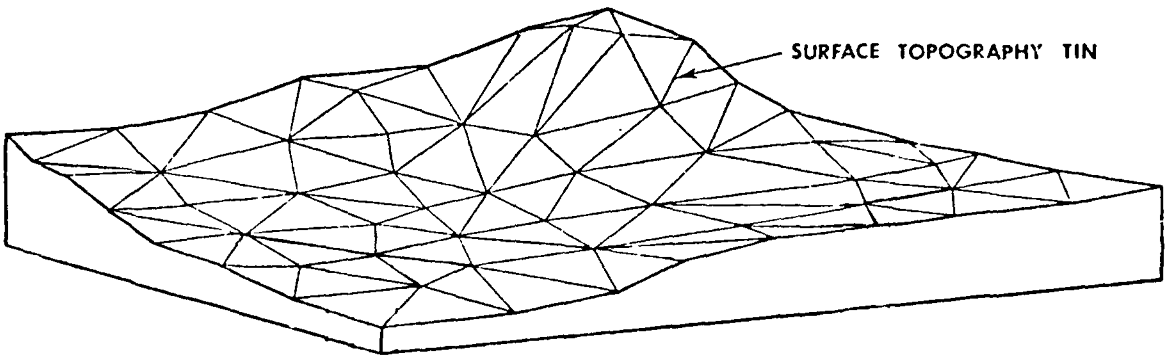

Figure 11. Perspective View of an Example TIN Topographic Data Base.

HARDAT
A UNIVERSAL HARVESTING DATA STORAGE AND RETRIEVAL SYSTEM[1]

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ABSTRACT

HARDAT is a computerized information storage, retrieval and analysis system developed to provide a standardized harvesting data base for use in research and equipment evaluation. Each individual record of the data base describes a timber harvesting system and operational performance data on a specific harvesting unit. Each record follows a classification system which includes variables describing the harvesting system, the characteristics of the timber stand and harvest site, the products produced, the production levels achieved, the equipment employed and the supplemental data identified. Analysis of the records on file in the data base and the summary output are achieved through the Statistical Analysis System (SAS).

INTRODUCTION

A wide variety of harvesting performance data has been collected for use in equipment evaluation, simulation modeling and for industrial harvesting operations control. The large quantity of data available became apparent in the conduct of a research project designed to evaluate the suitability of equipment for harvesting biomass. An initial phase of the study necessitated the collection and analysis of a wide spectrum of harvesting production and cost data from actual field performance trials as reported in research papers and a variety of unpublished data sources.

It soon became apparent that a computerized data base would be

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necessary to handle the large amount of data available. Other data bases exist, such as the one developed by Gochenour and Biller (1978), but were designed to meet other requirements. Further complicating the collection and data base design was the lack of standardization in data reporting. A decision was made to design a data storage, retrieval and analysis system that would satisfy the immediate requirements of the biomass harvesting project as well as provide a framework for reporting harvesting performance data that could also meet the general requirements of other users in research and industry.

HARDAT is the result of this effort. It provides a standardized basis for reporting harvesting data for use by logging managers and harvesting system researchers. HARDAT is currently operational on computers available to the Forest Engineering Research Project at Morgantown, WV and the SUNY College of Environmental Science and Forestry at Syracuse, NY. The heart of the data base is the design of the classification system to allow for a complete description of existing harvesting systems. Analysis and output are achieved through the readily accessible summary and statistical analysis capabilities of the Statistical Analysis System (SAS) software package.

HARVESTING SYSTEM CLASSIFICATION

The objective of the classification system was to completely and specifically describe the various harvesting equipment configurations in current use. Harvesting in this concept applies to all wood removal systems whether shortwood, longwood, or tree length.

Development of the classification scheme involved four major considerations. The stand and site conditions are viewed as input to the stump processing. Stump processing produces a product for the off-road transport (ORT) which moves the product (without processing) to the landing where further processing may take place. The result of the landing processing is a roadside product ready for transport to the mill. Highway transport is not considered as part of the data base. The following diagram illustrates the relationship of the four considerations.

I: TIMBER STAND & SITE → II: STUMP PROCESS → PRODUCT → III: ORT → IV: LANDING PROCESS → PRODUCT

Complete description of the equipment, the site, and the harvest conditions require identification of up to 196 variables for each record. Each record consists of field data for a specific site/equipment configuration describing the characteristics of the timber stand, the harvesting system, the products produced, the production levels achieved, the equipment employed and any supplemental data identified.

CHARACTERISTICS OF THE TIMBER STAND AND HARVEST SITE

A description of the timber stand characteristics and physical factors of the harvest area is achieved by entering values for the following variables.

1. unit size (acres)
2. avg. stand age (years)
3. wt. before cut (tons/acre)
4. wt. removed (tons/acre)
5. silvicultural system - 2 fields

   1st field - identifies this is a post harvest operation - another operation recently preceded this record

   2nd field - defines silvicultural system: clearcut, seed-tree, shelterwood-entry, shelterwood-overstory, thinning, selection, salvage, other

6. avg. yarding distance (feet)
7. avg. tree diameter (inches)
8. avg. tree height (feet)
9. defect of stand (%)
10. slope of stand (6 classes)

Stand information is expressed in terms of tons of material available before the cut and the tonnage removed. The use of tons may require some mental reorientation or the inclusion of a board foot or cords conversion factor. Forest types are based on Society of American Foresters forest cover types (Eyre, 1980).

HARVESTING SYSTEM

Three major components describe the harvesting system: processing at the stump and the products produced, off-road transportation, and landing processing.

Stump Processing

Two fields are used to describe the activity at the stump and the product that is available to the ORT equipment. The first character defines the felling process while the second character identifies the product mix available at the stump.

Stump process - 2 fields

1st field	2nd field
identifies the felling process: fell, limb, top; fell, limb, buck, top; fell, nothing	identifies the product mix at the stump: chips, fuelwood, pulpwood, sawlogs, tree length or whole tree

The equipment or method used is defined under equipment employed.

Off Road Transportation

Two fields are needed for off-road transport also. The presence of a B or N in the first field identifies whether bunching has taken place prior to the ORT function. The second character identifies if skidding, forwarding, helicopter or cable yarding was used to move the logs from the stump area to the landing. Codes available are:

Off-road transportation (ORT) - 2 fields

1st field	2nd field
B - bunching	GS - ground skidding
N - no bunching	TA - trailing arch
	IG - integral grapple
	IC - integral cable
	IO - integral other
	FR - forwarding
	CY - cable yarding
	HE - helicopter

Landing Processing

The landing area is described by a 3-field entry identifying the processing which takes place and the product(s) leaving the landing.

Landing - 3 fields

1st field

C - limb, buck	J - buck, pile
B - buck only	K - chip only
L - limb only	M - limb, buck, chip
N - nothing	O - limb, chip
S - sort only	P - buck, chip

2nd field

L - loading occurs	N - no loading occurs

3rd field

C - chips	H - sawlogs, chips
F - fuelwood	I - sawlog, pulpwood
P - pulpwood	J - sawlog, fuelwood
S - sawlog	K - sawlog, pulpwood, chips
T - tree length	L - pulpwood, fuelwood
W - whole tree	M - tree length, sawlogs
A - sawlog, posts, chips	N - fuelwood, pulpwood, sawlogs
	O - sawlogs, poles

PRODUCT DESCRIPTION

The dimensions of the forest products leaving the landing are recorded in terms of minimum scaling diameter and length. The fields used are:

1. fuelwood - 2 fields
   length (inches)
   minimum diameter

2. pulpwood - 2 fields
   length (feet)
   minimum diameter (inches)

3. sawlog - 2 fields
   minimum length (feet)
   minimum top diameter (inches)

4. tree length - 2 fields
   length (feet)
   minimum top diameter (inches)

5. other - 2 fields
   length (feet)
   diameter small end (inches)

6. specs. on file - last field
   Y - yes
   N - no

PRODUCTION DATA

This section records the production achieved by the given harvesting system. Production is expressed in tons per productive hour, on the assumption that weight provides a more accurate and consistent measure of production than either board feet or cubic feet. For a large operation, production data can be recorded individually for each of two ORTs, two landing processors and two multifunction machines. The variety of activities that could take place at the stump and the landing necessitated limiting the individual data records for all multiple machines. Data are combined for multiple machines used for felling, bucking, bunching, swinging and/or performing secondary landing processing.

1. felling (tons/prod. hr.)
   no. of fellers

2. limbing (tons/prod. hr.)
   no of limbers

3. bucking (tons/prod. hr.)
   no. of buckers

4. bunching (tons/prod. hr.)
   no. of bunchers

5. multifunction machine (MFM) 1 (tons/prod. hr.)
   No. of MFM

6. MFM 2 (tons/prod. hr.)

7. ORT 1 (tons/prod. hr.)
   no. of ORT
   avg. load/turn (tons/turn)
   avg. no. pieces/turn (pieces/turn)

8. ORT 2 (tons/prod. hr.)
   avg. load/turn (tons/turn)
   avg. no. pieces/turn (pieces/turn)

9. landing processor 1 (tons/prod. hr.)
   no. of landing processors

10. landing processor 2 (tons/prod. hr.)

11. swing (tons/prod. hr.)
    no.
    swing distance (feet)

12. secondary landing processor (tons/prod. hr.)
    no. of sec. land. processors.

EQUIPMENT EMPLOYED

Of major importance is the description of the type of machine used and the associated owning and operating costs. Data for each of the variables shown below are repeated for each machine used in the various harvesting functions. Costs are based on productive hours in 1980 dollars. Total owning and operating costs include labor costs with fringe benefits. The "specs on file" category is used when additional information on the machine is available.

1. felling -
   machine code
   manufacturer's code
   horsepower
   weight (lbs.)
   est. 1980 fixed costs ($/prod. hr.) Use 8%/yr. inflation
   est. 1980 variable costs ($/prod. hr.)
   est. 1980 total owning and operating costs ($/prod. hr.) with labor
   est. 1980 labor costs ($/sch. hr.)
   est. utilization (% prod. hr. divided by sch. opr. hrs.)
   est. availability (% sch. opr. hrs. - mech. delays divided by sch. opr. hrs.)
   specs. on file (Y-yes, N-no)

2. limbing -
   machine code
   manufacturer's code
   horsepower
   weight (lbs.)
   est. 1980 fixed costs ($/prod. hr.)
   est. 1980 variable costs ($/prod. hr.)
   est. 1980 total owning and operating costs ($/prod. hr.) with labor
   est. 1980 labor costs ($/sch. hr.)
   est. utilization (% prod. hr. divided by sch. opr. hrs.)
   est. availability (% sch. opr. hrs. - mech. delays divided by sch. opr. hrs.)
   specs. on file (Y-yes, N-no)

FLAGGED TOPICS

A variety of information is often associated with each record that is difficult to classify in any of the above categories. The purpose of this section is to identify, by flagging, if environmental impacts, mobility of the equipment in terms of travel between landings and jobs, regression equations spelling out relationships which may have been developed for conversion factors or production rates, or fuel consumption were reported with the data. The additional information available under flagged topics is summarized and recorded by record number outside of the main data base. Sorting on flagged topics will result in a listing of numbers for the records with flagged topics. The topics available for flagging are:

1. environmental impacts (Y/N)
2. mobility data (Y/N)
3. biomass conversion factors or equations (Y/N)
4. production regression equations (Y/N)
5. fuel consumption (Y/N)

DATA RECORDING AND ANALYSIS

With the large numbers of variables that could be used to define a harvesting system and the large number of records sought, selection of a computerized system which required a minimum of programming was essential. SAS, the Statistical Analysis System developed at North Carolina State University (SAS Institute, Inc., 1979), manages the information and retrieval system and provides the analysis and output capability. A wealth of statistical analysis procedures are available, ranging from simple descriptive statistics to more complex statistical analysis for variable comparison.

DATA RECORDING

Harvesting data from personal interviews, research articles and industry records are first recorded on coding forms as shown in Figure 1. The letters on the right-hand side of the coding form are names given to each variable for use with SAS procedures. Each record is assigned a record number and a source number. The record number identifies each unique record while the source number identifies the origin of the data. More than one complete record may be obtained from a single source. The more than 150 records collected for the biomass harvesting project were obtained from a total of 55 sources representing studies performed throughout the northeastern, north central and southeastern areas of the United States.

Data are currently entered via punched cards, thus providing a relatively permanent record of the data in the card format. Within the system, the disk is used for primary storage and data analysis with tape used only as a backup for the stored records.

ANALYSIS

SAS provides a variety of statistical methods for analyzing data the data base. By means of appropriate SAS procedures it is possible to calculate new descriptors such as cost per ton for off-road transportation equipment, or to present data in different formats such as a plot of one variable against another or as one of a host of regression procedures.

Figures 2-4 illustrate initial plot procedures from SAS as applied to selected records in the data basse. Figure 2 is the plot of the production shown in 33 records of wheeled skidders and farm tractors against horsepower. Initial data plots can show situations for further exploration, such as the jump in production for skidders over 70 horsepower. Notice that there were an additional 16 records for which either horsepower or production in tons was not recorded.

Figure 3 is a plot of the production shown in 29 records for cable yarders against horsepower. The general upward production trend with increasing horsepower could be further explored by grouping cable yarders by broad horsepower classes. Figure 4 illustrates an increasing average load weight with increasing horsepower. Records for cable yarders were limited to approximately 120 horsepower in keeping with the biomass focus of the study. In both cable yarder plots a number of observations did not have the complete desired data.

Within the data base, substantial numbers of observations for similar horsepower machines operating under a variety of conditions permit study of the effects of certain variables with quantifiable statistics. Where sufficient number of records exist, such as average dbh and/or tons per acre removed for cable yar-

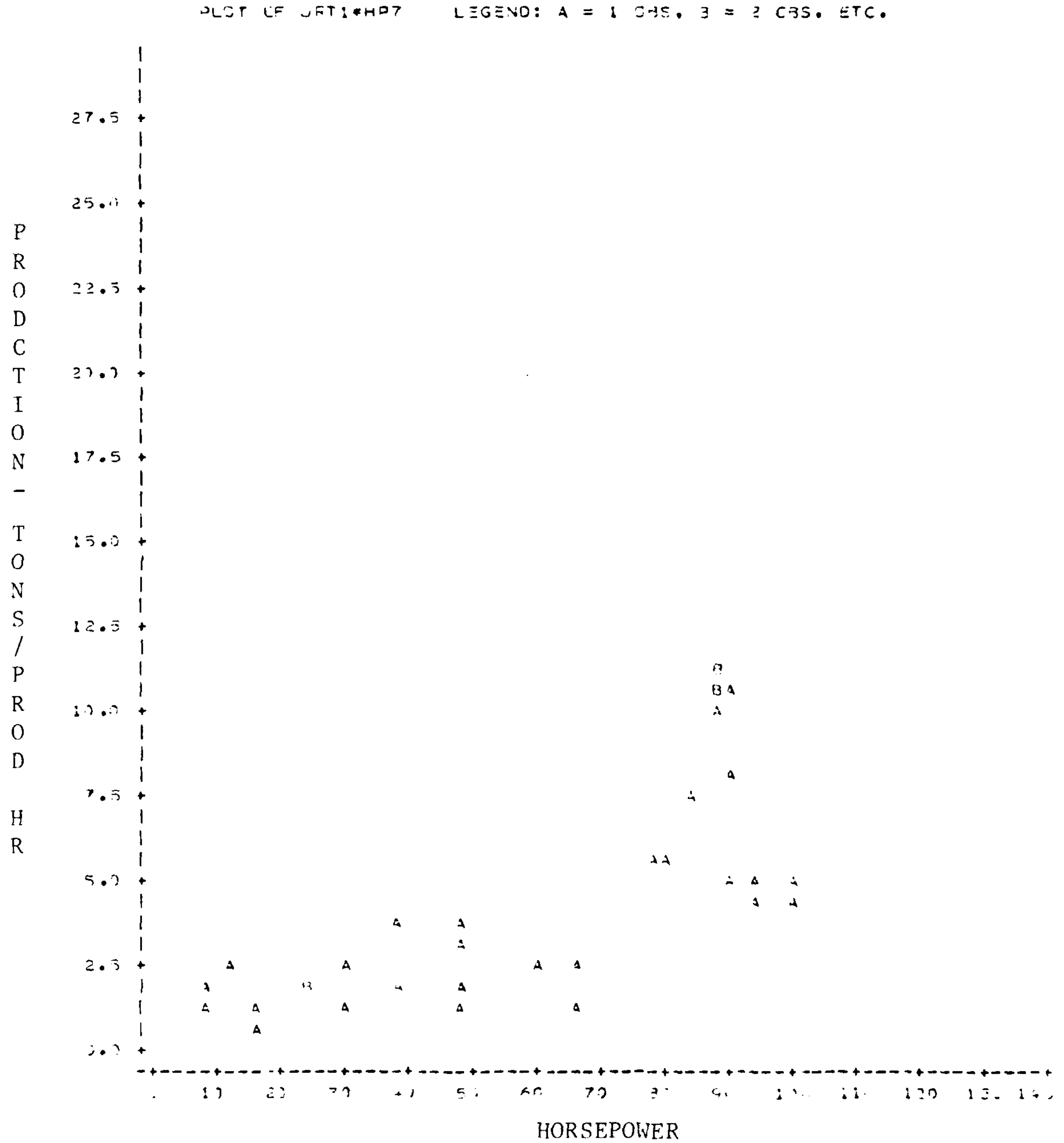
F. Equipment Employed

	Card columns	Units	Record Card
record number	01 02 03 04 (7)		
7. ORT 1 -			
machine code	06 07		MC7
manufacturers code	08 09		MA7
horse power	10 11 12		HP7
weight	13 14 15 16 17	lbs.	WT7
'80 fixed cost	19 20 21	$/prod.hr.*	FC7
'80 variable cost	23 24 25	$/prod.hr.*	VC7
'80 tot. owning & operating cost	27 28 29	$/prod.hr.*	0067
'80 labor cost	31 32 33	$/sch.hr.*	LC7
est. utilization	35 36	%	EV7
est. availability	38 39	%	EA7
spec. on file	40	Y or N	SOF7
8. ORT 2 -			
machine code	42 43		MC8
manufacturers code	44 45		MA8
horsepower	46 47 48		HP8
weight	49 50 51 52 53	lbs.	WT8
'80 fixed cost	55 56 57	$/prod.hr.*	FC8
'80 variable cost	59 60 61	$/prod.hr.*	VC8
'80 tot. owning & operating cost	63 64 65	$/prod.hr.*	OOC8
'80 labor cost	67 68 69	$/sch.hr.*	LC8
est. utilization	71 72	%	EV8
est. availability	74 75	%	EAK8
specs. on file	76	Y or N	SOF8

FIGURE 1. CODING FORM FOR ORT EQUIPMENT EMPLOYED.

TONS PER PROD. HR. VS HORSEPOWER

WHEELED SKIDDERS AND FARM TRACTORS

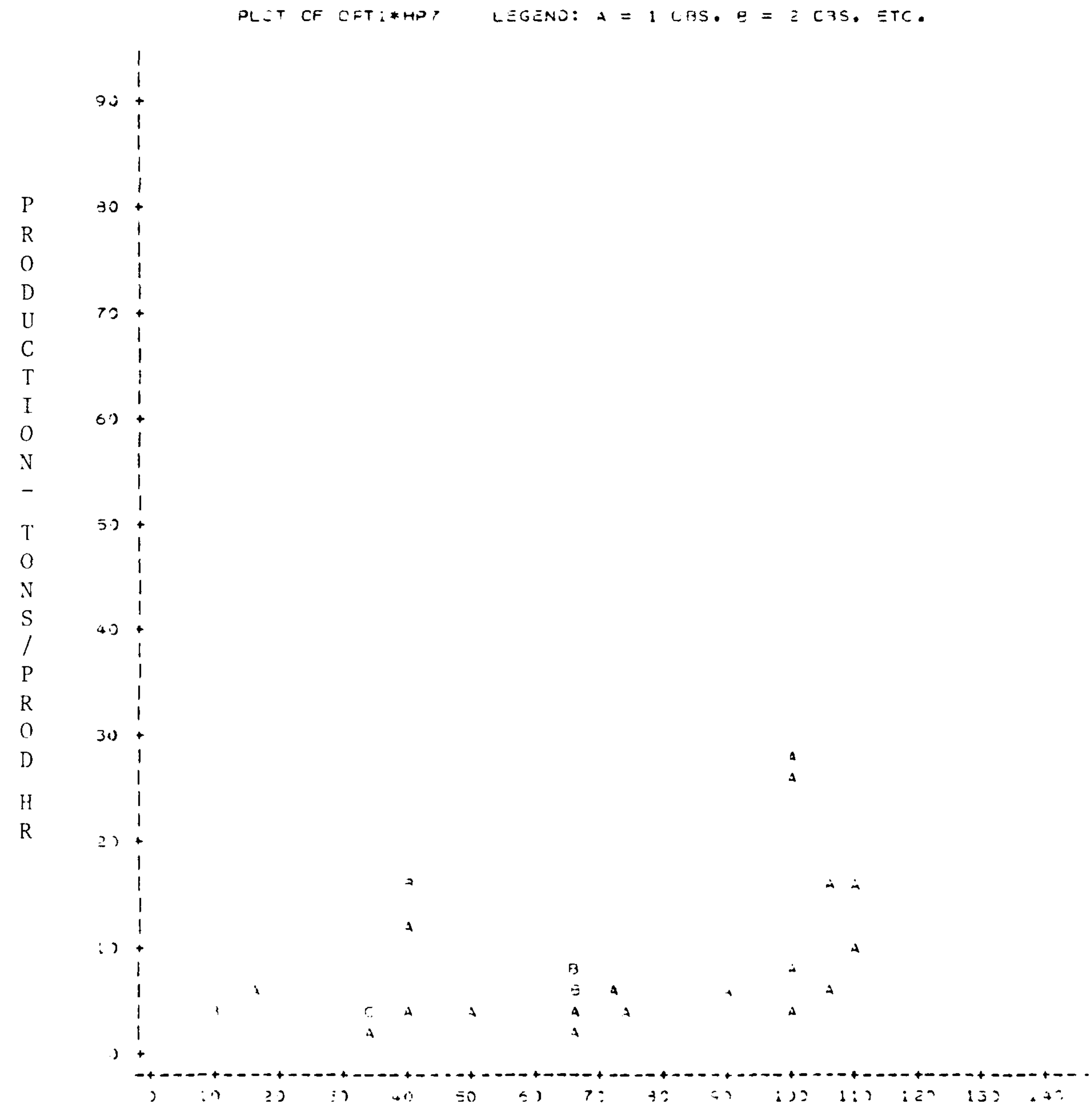


NOTE: 16 OBS HAD MISSING VALUES

FIGURE 2. PLOT OF PRODUCTION VS. SKIDDER AND FARM TRACTOR HORSEPOWER

TONS PER PROD. HR VS. HORSEPOWER

CABLE YARDERS

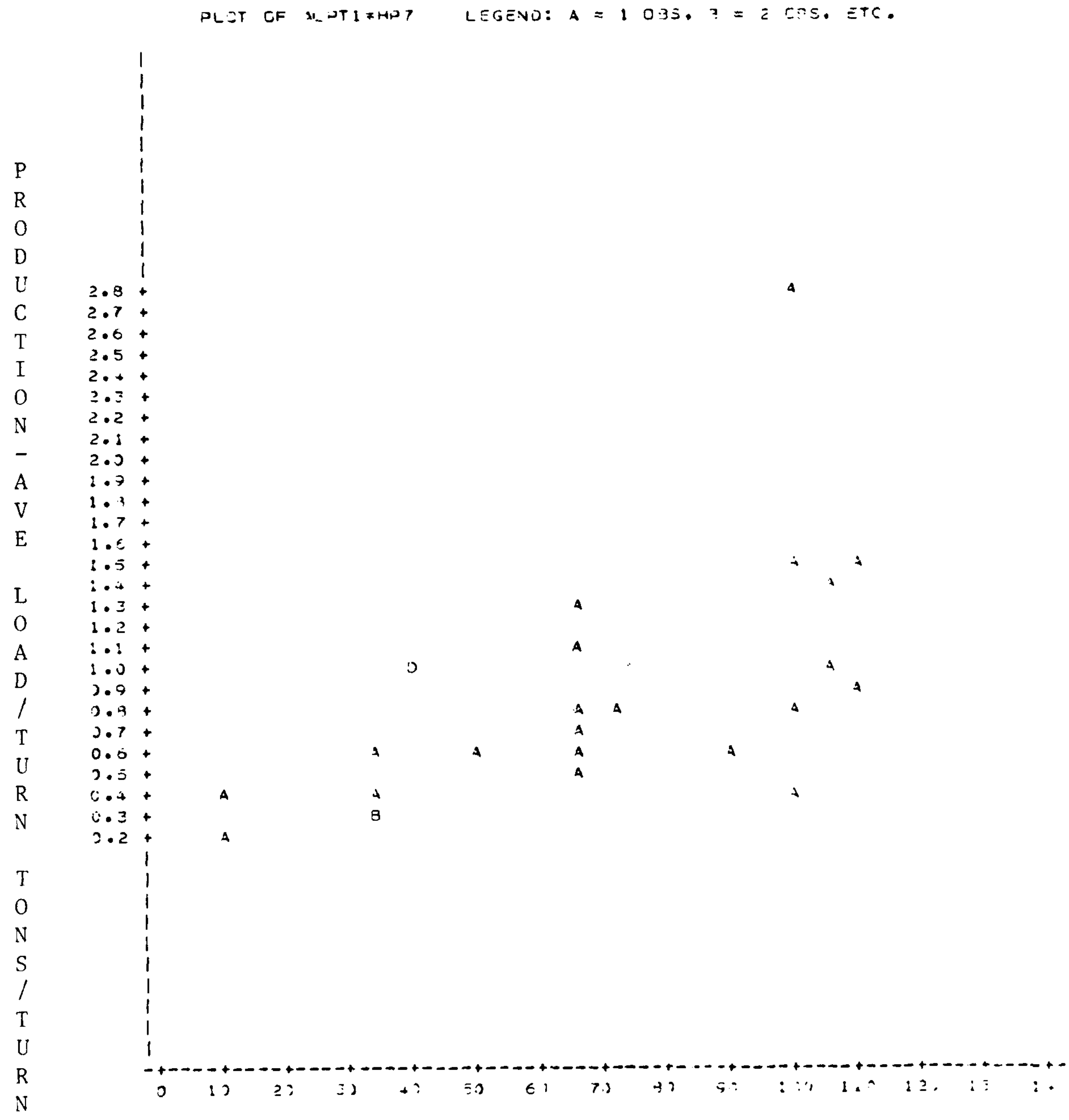


NOTE: 17 OBS HAD MISSING VALUES

FIGURE 3. PLOT OF PRODUCTION VS. CABLE YARDER HORSEPOWER

AVE LOAD (TONS) PER TURN VS HORSEPOWER

CABLE YARDERS



NOTE: 19 OBS HAD MISSING VALUES

FIGURE 4. PLOT OF AVE. LOAD PER TURN VS. CABLE YARDER HORSEPOWER

ders, the relationship of tons removed or average dbh can be determined as a function of horsepower class.

In addition to the use of the data base and SAS procedures for the biomass harvesting study needs, the data base can also supply needed production distributions for use in simulation modeling.

APPLICATION AND DISCUSSION

HARDAT has proven to be a useful data base to meet the needs of the biomass research project for which it was initially developed. All harvesting systems encountered were readily described by the variables in the classification scheme, after a few early modifications. The framework of the classification scheme provided a systematic way of recording data from the various sources. The most frustrating aspect has been to locate a promising source, only to find a critical value missing so that the record could not be completed. Often values describing the timber stand in which the harvesting system is operating will be missing, thus requiring extensive calculations or assumptions to complete the record. A knowledge of the timber stand characteristics is important in the biomass project. A standardized reporting system, whether that used in HARDAT or some other approach, would be helpful in making harvesting data useful on a wider basis.

Completion time for coding a single record varied from approximately 30 minutes, where all of the data in the source were in a similar format, to over 4 hours where calculations or assumptions had to be made to complete the record. There is a substantial investment in a data base as described here. Means of making this data base available to other organizations could be explored. Obviously, data sources would need to be kept confidential as is currently being done by maintaining the data source listing separate from the base.

The HARDAT harvesting system classification scheme coupled with the Statistical Analysis System has proven to be useful in storing, retrieving, and analyzing quantities of harvesting data. The classification scheme should also prove useful to other researchers and logging managers.

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TIME ANALYSIS OF FOREST HARVEST OPERATIONS

Thomas C. Bjerkelund

The program committee regrets that Dr. Bjerkelund's paper was received too late to be included in the proceedings. We thank Dr. Bjerkelund for his oral presentation of this subject at the symposium.

MOUNTAIN LOGGING WITH THE BITTERROOT MINIYARDER

by

Frederick W. Cubbage
August H. Gorse IV

ABSTRACT

The Forest Service recently developed a small cable yarder for use in the mountains that has been tested on Region 8 National Forests. The small-scale yarder was used during the summer of 1983 by a local operator on the Chattahoochee National Forest in North Georgia.

Time study data was taken on the yarder during its period of operation. The yarder, which had a 2000-pound mainline pull, performed very well within the limits of its capacity. It could usually pull tree-length material which was smaller than 12 inches at the stump. Larger trees required bucking into two or more logs. In favorable conditions, cycle times were consistently less than 5 minutes. However, yarder pull capacity sometimes required logs to be unhooked, cut into pieces, and rehooked, which slowed some cycles. Standing trees, brush piles, or tree felled on top of each other could also prevent successful turns.

Overall, the yarder showed potential for good cycle times. Good layout and planned felling would help the yarder be as productive as possible.

MOUNTAIN LOGGING WITH THE BITTERROOT MINIYARDER

Frederick W. Cubbage
August H. Gorse IV

INTRODUCTION

Interest in cable yarding systems for harvesting wood in the Eastern United States has increased dramatically in recent years. Articulated, rubber-tired skidders have generally been efficient and economical, even in the mountains, if enough log roads and skid trails are established. However, as the terrain becomes steeper, both overall logging and road costs and environmental damage increase significantly when skidders are used. Cable yarding systems have been proposed as one method to overcome these problems.

In the last five years, cable yarders have been tested and timed in several Eastern mountain locations (Fisher and Peters 1982). Most have been considerably smaller than those commercially employed in the West. Recently, the U.S. Forest Service Equipment Development Center in Missoula, Montana developed a very small-scale system named the Bitterroot miniyarder (USDA Forest Service 1983). The miniyarder has been tested on National Forests in the East in 1983 and 1984. In this paper, the results from a study of the yarder on the Chattahoochee National Forest near Clayton, Georgia are reported. A companion paper (McMinn 1984) reports some of the environmental effects.

YARDER CONFIGURATION

The Bitterroot miniyarder is probably the smallest yarding system to operate in the United States. The machine is a compact, lightweight, two-drum, live-skyline yarder (Figure 1). It was designed to remove light slash, thinnings, and logging residue of pulpwood or firewood size. The yarder is very portable, and may be mounted on a small trailer or a 3/4-ton pickup truck.

A recent American Pulpwood Association Technical Release (Domenech 1983) summarizes most of the technical specifications for the yarder that follow:

Weight: 1,600 pounds rigged

Engine: 18 horsepower Briggs and Stratton, twin cylinder, air-cooled, electric start, remote fuel tank

Transmission: Sundstrand series 15 hydrostat

Skyline and Mainline Drums: 800 feet of ½-inch cable, 0-2000 pounds line pull, 0-400 feet per minute line speed

Axle: Dana Spicer GT-20 with 72-tooth spur gear

The authors are Assistant Professor and Graduate Research Assistant, respectively, at the University of Georgia School of Forest Resources. Partial funding for this study was provided by The Georgia Forestry Commission, Research Division.

Figure 1. Typical Live Skyline Yarder Configuration

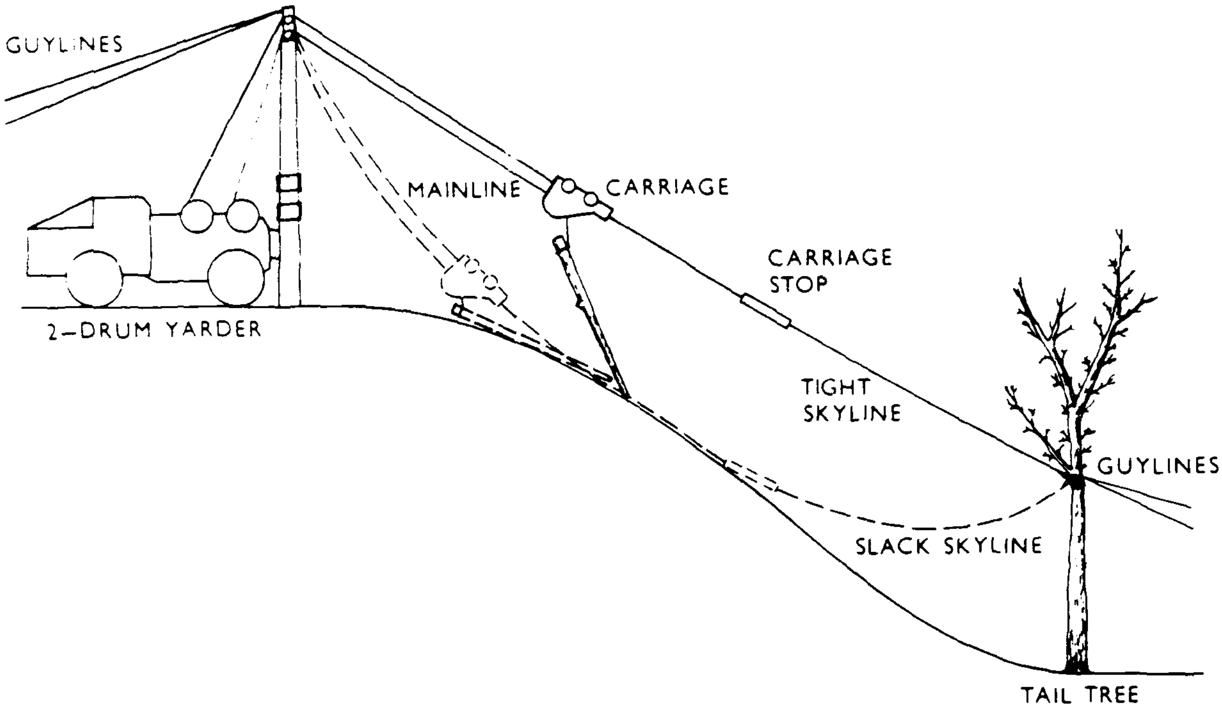
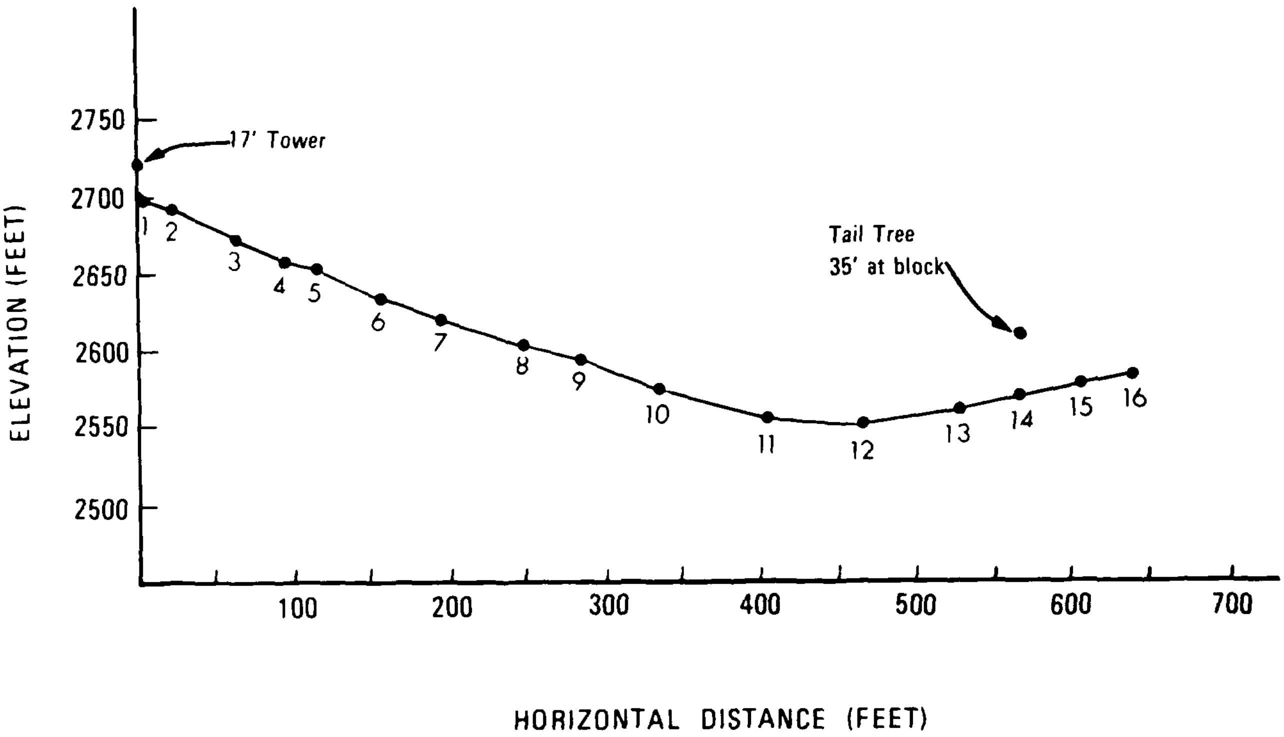


Figure 2. Logging Profile for Study of Bitterroot Miniyarder



Mainline Clutch: dog type
Brakes: Band type, mechanically operated, 12 3/5-inch diameter
Boom: 2½-inch pipe, A-frame, 17½-feet long, manually raised and lowered
Controls: 15-feet remote box, mechanical push/pull cable
Carriage: Mini-Christy with mechanical clamping stop, 80 pounds
Communications: 1-watt walkie-talkies

STAND AND CREW

A stand cruise was made before the harvest. Volume estimated by the Total Biomass Cruise Program (Clark and Field 1981) was about 10.5 cords per acre to a 4-inch top. The stand consisted primarily of oaks, yellow poplar, red maple, blackgum, and white pine, mostly in the pole-size tree classes. The tract was sold to a local logger as a firewood sale. He removed most of the hard hardwoods--chestnut oak, red oak, white oak and hickory--and left most of the maple and poplar and all of the blackgum. He harvested all the white pine for sale to a local sawmill. The harvest generally looked like a clearcut with a few patches of standing undesirable stems.

The harvesting crew during the study was composed of different persons, leading to variable results. Trained Forest Service personnel operated the yarder the first day, and the local logger learned to operate the equipment the rest of the time. A local resident worked as sawyer and choker setter for a few days, but soon quit. Various Forest Service and University of Georgia personnel served as choker setters for the remainder of the study. The operator worked part-time at other jobs, so he cut trees and ran the yarder only periodically.

The sale consisted of about five acres, but due to the sporadic operation of the crew, only two corridors (about one acre) were cut and yarded with the Bitterroot. Slopes on the site ranged from minus 50 percent at the middle of the mountain and gradually changed back to about plus 20 percent in the far side of the profile (Figure 2). For the first corridor, the chord slope from the 17-foot tower to a block 35-feet high on the tail tree was 19 percent. Logs were yarded to a split deck--the yarder was stationed about six feet above a lower log landing.

STUDY METHODS

Operation of the miniyarder was timed continuously. Elemental and total cycle times were measured by two observers. One was stationed in the woods to time hook, lateral winch, and loaded travel. The other worked at the deck, timing travel empty, unhook, and full cycle times, as well as making log measurements.

Travel empty was timed from the release of the carriage at the top of the hill until it hit the stop. Hook times were recorded from the time the carriage hit the stop until the operator began tightening the mainline after being radioed by the choker setter. Lateral winch was measured from the tightening of the mainline until the carriage released from the stop. Travel loaded consisted of inhaul from the stop until the operator slacked the skyline, and unhook continued until the carriage began its descent again. Full cycle times included all the components from one carriage descent to the next. Delays were timed as they occurred, keeping track of both delay times and the element during which they occurred.

Log lengths and diameters at both ends were measured at the deck, providing data for calculating log volumes by Smalian's formula. From the volume equations, the log weight was calculated using the weight per cubic foot of wood (Timson 1975, Clark 1983). Horizontal distance down the corridor from the yarder was measured and flagged at 50-foot intervals. This was converted to slope distance for subsequent use in the analysis. Lateral yarding distance--measured on a perpendicular from the log to the skyline--was estimated visually by the timekeeper in the woods, who also noted the horizontal distance for each turn.

DATA ANALYSIS

Various data summaries are useful in analyzing machine productivity. Table 1 summarizes the time, volume, and terrain data collected during the study. Since the yarder size is unique, data from a few studies of larger skyline yarders are depicted with that from the Bitterroot study in Table 2.

Many characteristics of the yarder itself and in comparison with other yarder systems are worth noting. First, compared with other yarders (Fisher and Peters 1982), the Bitterroot is indeed small. It has an 18-horsepower engine, ¼-inch cable, and an approximate assembled cost of about $15,000. The other systems listed in Table 2, which would be considered small in the West, had at least 100-horsepower engines, ½-inch or greater cable, and yarder costs ranging from $55,000 to over $100,000. Accordingly, the volumes moved per turn with the Bitterroot were considerably less--only about 1/3 to 1/5 as much as the other systems.

The average lateral distance yarded by the skyline systems shown in Table 3 was similar, about 35 feet. The Ecologger and Urus averaged longer slope yarding distances during their studies, while the GP Slackline was slightly less. The Bitterroot usually hauled only one log per turn, as did the Urus. The Ecologger and Slackline yarders had larger cable sizes and engines, and averaged more trees per turn.

Elemental Times

The elemental times, excluding delay, for the Bitterroot were faster than for the other systems timed in the East. Average slope yarding distance for the Bitterroot was shorter, so average travel empty--the time it takes the carriage to fall down the skyline--should take less time.

The hook times of less than one minute were also much less for the Bitterroot than those found in other studies. Hooking only one tree speeds work. Also, the workers would set one choker in the woods while one log was being pulled to the deck, which was very efficient. In addition, with the live skyline system, about 50 feet of mainline were thrown free to the ground when the carriage hit the stop. The cable was light and easy to pull and the logs were so small that they seldom became buried in the ground. All these factors contributed to the fast hook times.

Average time required to winch a tree laterally (0.86 minutes) was greater with the Bitterroot than with other systems studied, and highly variable as well. This reflects a limitation of a small machine. Lateral yarding demands great force to break logs free from the ground and pull

Table 1. Characteristics of Selected Bitterroot Miniyarder Variables for Uphill Yarding.

Variable	Mean	Standard Deviation	Range	Number of Observations
Cycle Time Including Delay (mins):				
Travel empty	0.30	0.09	0.13 - 0.67	123
Hook	0.98	0.96	0.08 - 7.53	114
Winch lateral	1.29	1.97	0.13 - 13.18	141
Travel loaded	0.95	0.40	0.38 - 3.23	140
Unhook	0.88	0.81	0.25 - 5.73	101
Full cycle	3.96	2.25	1.77 - 16.68	99
Delay per cycle	0.63	2.65	0.41 - 11.75	29
Tree Measures:				
Stems per turn	0.99	0.30	0 - 2	144
Turn volume (cu. ft.)	9.38	4.31	.41 - 20.99	137
Turn weight (lbs.)	567	268	25 - 1322	137
Stem length (ft.)	20.7	8.3	6 - 46	142
Butt diameter (in.)	10.6	2.89	4.0 - 16.9	142
Top diameter (in.)	7.4	3.32	2.0 - 15.0	142
Yarding and Terrain:				
Slope distance (ft.)	274	109	107 - 473	144
Lateral distance (ft.)	40	32	5 - 125	144
Percent slope	-25	-	(-50) - (+16)	-

them through brush and potential snags. Lateral yarding times should be greater for a low-power machine than for a high-power machine that has greater pulling capacities. Hooking the "wrong" log in a pile would prevent lateral yarding and require rehooking to a different log. During lateral yarding, large residual hardwood tops or standing trees could impede operations, requiring the operator to consecutively engage and disengage the transmission in an attempt to shake loose a "hung" tree.

Generally, once the logs reached the carriage, there were few problems in hauling in the mainline. On a couple of occasions, the butt end dug into humps on the slope, but it was easily rehooked and pulled out. On two occasions, the skyline snapped in the middle of inhaul, much to the consternation of the crew and observers who watched the cable and stop fly past. The logs yarded at the time were not excessively large, weighing about 800 pounds. On the Chattahoochee, ¼-inch aircraft cable was used for the skyline. It seemed to kink rather easily during system rigging and use, which may have reduced its strength enough to break. Wire rope of ¼-inch or 3/8-inch diameter probably would be more flexible and stronger.

Table 2. Average Study Data for Selected Yarding Systems.

Variable	Yarder and Study			
	Bitterroot Cubbage and Gorse 1984	Ecologger Fisher *et al.* 1980a	CP Slackline Biller and Fisher 1982	Urus Fisher *et al.* 1980b
Yarder characteristics:				
Yarder type	live skyline	live skyline	live skyline	standing skyline
Engine horsepower	18	130	106	100
Max. skyline length (ft.)	600	1000	-	1100
Cable diameter (in.)	1/4	11/16	3/4	1/2
Terrai. and load:				
Slope distance (ft.)	274	369	246	430
Lateral dist. (ft.)	40	30	36	37
Logs per load	.99	1.35	2.90	1.02
Avg. load (cu. ft.)	9.38	52.8	52.20	32.46
Cycle times without delays (min):				
Travel empty	0.30	0.55	0.52	0.55
Hook	0.79	3.11	2.25	1.30
Winch lateral	0.86	0.56	0.38	0.57
Travel loaded	0.93	1.02	1.39	1.88
Unhook	0.85	1.75	0.96	0.79
Full cycle	3.53	7.13	5.50	4.92
Cycle delays (min):				
Travel empty	0.02	-	0.18	0.04
Hook	0.19	-	0.08	0.02
Winch lateral	0.44	-	0.30	0.51
Travel loaded	0.02	-	0.23	0.10
Unhook	0.02	-	0.29	0.19
General delay (move stop)	0.25	-	0.20	0.65
Total cycle delay	0.63	2.07	1.37	1.52
Cycle time w/delay (min):	4.21	9.20	6.87	6.98

Note: Cycle times were calculated independently, thus do not agree with the sum of the element times, due tc different numbers of observations.

Unhook times were similar to those found in other studies. With the split-deck arrangement, it took an average of less than one minute for the operator to clamber down from the upper deck, unhook the log, and climb back up. Full cycle times of about four minutes for the Bitterroot were consistently less than those timed on other skyline operations, due to the combination of factors discussed above.

Delay Times

The fact that total cycle delays were less than for other systems seems less explicable than the fast full cycle times. Probably few delays were recorded because of the inexperience and sporadic work habits of the crew. Problems that might have caused minor delays with other systems and operators tended to cause complete shutdowns during this study--thus being classed as down time, not delay time.

Most problems, such as a stuck log, slipping cables, or brake adjustments, initiated a complete system shutdown to drop the skyline, cut free all the logs in an area, rewind the cable, or similar actions. Repairs were usually accompanied by lengthy breaks to talk about general progress and current events. Therefore, the data indicating few delays is not completely reliable. Cycle and delay times were relatively small, but overall system down time was excessive.

Although the times were not large, examining the distribution of delays is informative. Few delays occurred during travel empty. When the system was first rigged, sometimes the chokers did not weigh enough to trip the carriage release mechanism; the mainline would flip up and wrap around the skyline at the stop. This was easily remedied by adding a weight to the mainline just above the choker hook.

Significant delays occurred in hooking logs, more than reported in other studies. Hooking logs that could not be pulled, requiring rehooking, was one common problem. Finding logs amidst the brush was also difficult at times. Communication was the largest problem. The 1-watt walkie-talkies received CB chatter from all over North Georgia, but could barely broadcast from the bottom to the top of the hill. They should, but did not, have new batteries every other day, and ceased working when wet or dropped. Many turns required shouts or hand signals to get the operator to begin lateral yarding. The expensive, but effective, horn system used in the West would be a worthwhile improvement for a serious operation.

Lateral winching also included large average delays, caused by trees that were felled on top of each other and by snagging the logs on residual tops and trees. Once the carriage released from the stop, delays were minor. The carriage stop had to be moved periodically, but only took about 30 seconds to 3 minutes--adding only a small amount of time that was classed as general delay. When the skyline snapped, finding the stop in the brush, rewinding the drums, and stringing the carriage usually took at least ½-hour. The operator had no tree-climbing gear, so rigging the tail tree by throwing a rope through the 25-feet high fork took about an hour or two both times it occurred.

The operation harvested logs only periodically, so it was not possible to estimate total operating, delay, down, set-up, and move times. In the six days that operations were observed, the system had a scheduled-hour basis of approximately 30 hours. Times of 552 minutes were recorded during this period, indicating that the yarder operated only about 30 percent of the scheduled hours. Ninety of the 552 minutes consisted of delay--about

16 percent. This is somewhat less than the 12 to 34 percent found in other studies (Fisher and Peters 1982), but is probably due to the tendency to take major rather than minor breaks, and problems in classifying down and delay time caused by the machine versus that caused by the crew.

REGRESSION EQUATIONS

In addition to the average yarding times reported in Tables 1 and 2, regression equations were estimated for most elemental times and for the full cycle. All the factors that were recorded and thought to affect yarding times were tested as independent variables for predicting the dependent times. Many prior studies have predicted yarding times as linear relationships between the dependent and independent variables such as lateral yarding distance, slope distance, log volume, and number of logs (i.e. Fisher *et al.* 1980a, 1980b; Koger and Sherar 1982). However, the data collected in this study appeared to be non-linear for many of the yarding elements. Therefore, various transformations were made in order to estimate yarder functions better.

The SAS computer package (SAS Institute 1982) was used to help plot relationships, perform regression analyses, examine residual patterns, and choose the appropriate model. When developing equations, the delay times obscured the fundamental relationships determining elemental times. Thus, elements containing delays were deleted from the data set, and the regression estimates, which are summarized in Table 3, were made only on the remaining data. If the regressions are used for prediction, delay times should be added in order to estimate production correctly.

Statistically significant equations were estimated for each elemental and full cycle activity except unhooking. In many instances, regressions with larger coefficients of determination could be estimated by using variables unique to the study, such as day number, choker, or corridor number. The equations reported in Table 3 were selected because they are more useful for general applications.

The explanatory power of the regressions is not large, but is typical of most harvesting and empirical field studies. It is difficult to quantify and measure everything that occurs in harvesting. Converting most of the equations to non-linear form did greatly improve their coefficients of determination and the random appearance of their residual plots. Results from the regressions are fairly straightforward, albeit difficult to interpret given the transformations made on the variables. All the equations estimated confirm the logical effects of independent variables on elemental times. Increasing turn weights or yarding distances always increased turn times.

Travel empty time is inversely related to slope distance, indicating that it takes time for the carriage to build speed; eventually time asymptotically approaches being a linear function of the slope distance tc the stop. Hook time is primarily a function of lateral yarding distance. Lateral winch times are explained best by the lateral yarding distance and log weight. As expected, time to travel loaded up the skyline also depended on the weight of the turn and the slope distance. For both full cycle and slope yarding, the interaction between distance and weight was a significant independent variable. This serves as a proxy for the amount of work performed to move the log up the hill, as suggested by Robinson and Fisher (1983). No variables were significant in predicting unhook time, including number of logs, pile size, or log weight.

Table 3. Regression Estimates for Log Yarding Times

Yarding Element	Regression Equation	R^2	F Ratio
Travel Empty	$1/\text{Travel}_{min} = 5.8703 - 0.009226\ (\text{slope distance}_{ft})$	0.52	130.9
Hook	$\text{Log}_{10}\ (\text{Hook}_{min}) = -0.2504 + 0.00236\ (\text{lateral distance}_{ft})$	0.18	23.1
Winch Lateral	$1/\text{Winch}_{min} = 2.2929 - 0.0009615\ (\text{turn weight}_{lb}) + 6.00043\ (1/\text{lateral distance}_{ft})$	0.13	8.7
Travel Loaded	$1/\text{Travel}_{min} = 6.841236 + 0.0005153\ (\text{turn weight}_{lb}) - 1.160833\ (\log_{10}\ (\text{turn weight}_{lb} \times \text{slope distance}_{ft}))$	0.37	38.5
Full Cycle	$1/\text{Full Cycle}_{min} = 0.999786 - 5.867866\ (1/\text{turn weight}_{lb}) - 0.0004514\ (\text{lateral distance}_{ft})^{1} - 0.125545\ (\text{Log}_{10}\ (\text{turn weight}_{lb} \times \text{slope distance}_{ft}))$	0.17	5.4

[1] Significant at alpha = .10; other variables in all equations significant at alpha = .05. All regressions significant at alpha = .01.

For the data from this study, full cycle regressions with the greatest explanatory power ($R^2 = 0.30$) always included the day number--an indicator of experience with the machine. However, so few days were observed that such an equation would not apply to long-running operations. Therefore, the equation reported in Table 3, which uses slope distance, lateral yarding distance, and turn weight as independent variables, was chosen as the best for wider applications. Using the full cycle equation, average production, excluding delays, would be about 180 cubic feet per operating hour, using the average turn volumes and yarding distances. Production with the observed delays and down time included would be much less, about 45 cubic feet per scheduled hour.

DISCUSSION

The results from this study lead to several observations. The times for the Bitterroot live skyline system were quite fast, better than those found for large machines in other studies. But, the average cubic foot production per hour was much less than the systems with larger cables and engines. Due to problems with the crew observed, it was not possible to estimate realistic production rates per scheduled hour. Relatively few minor delays were encountered during logging, probably due to the crew's tendency to take major rather than minor breaks. Down time during the study was excessive compared with other yarders. The study was performed as the crew learned to operate the equipment, and the crew was also rather loosely organized. Therefore, down times would be expected to be great. Down times might also be large in long-running operations because small equipment is less durable than large. However, it was not possible during this short study to accurately separate crew or machine caused down time, so specific conclusions cannot be made.

The miniyarder requires that large trees be bucked into short lengths in order to be hauled into the deck. The smallest safe working payload for the observed set-up was roughly 800 to 900 pounds at the smallest deflection point on the skyline, although many larger logs were yarded up the hill. A 3/8-inch rather than the 1/4-inch cable could increase the safe working capacity of the yarder, but many turns would still be limited by engine horsepower.

The loggers in this study cut the trees and let them fall in a random pattern, making it difficult to yard some logs. Residual hardwood tops and standing trees also impeded lateral yarding. As such, use of the yarder for thinnings will require trained sawyers and operators. Trees will need to be felled directionally with a clear path to the skyline and the stop must be moved often to prevent residual trees from snagging the load.

Overall, the miniyarder does have potential applications in the East. Its small size and limited power will prevent widespread commercial adoption, but its portability and ease of operation will make it available for small loggers trying alternatives to skidder logging on steep slopes. Its use will also familiarize loggers in the East with cable yarder operations. By promoting cable systems, it may help increase their use in logging environmentally sensitive areas.

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SOIL DISTURBANCE BY FUELWOOD HARVESTING WITH A CONVENTIONAL GROUND SYSTEM AND A CABLE MINIYARDER IN MOUNTAIN HARDWOOD STANDS

James W. McMinn[1]

ABSTRACT

Fuelwood harvests were conducted in two hardwood stands in the mountains of north Georgia. In one stand timber was moved to the landing with a rubber-tired cable skidder, and in the other with a skyline miniyarder. Degree of site disturbance was estimated on systematic grids of sample points. With the rubber-tired skidder, mineral soil was exposed on about 37 percent of the logged area. With the miniyarder, virtually no mineral soil was exposed.

INTRODUCTION

Since the oil embargo of a decade ago, industries, institutions, and homeowners have all increased their use of fuelwood substantially. The potential fuelwood harvest in the Southern Appalachians is especially large because forests there contain large inventories of hardwoods that are too low in quality for conventional wood products. Utilization of these low-grade hardwoods for fuel could result in multiple benefits. Fuelwood harvests could boost depressed local economies and upgrade forest stands for the production of both conventional products and fuel. Harvesting costs and potential site degradation, however, currently limit the development of low-quality mountain hardwoods for fuel. This presentation focuses on the potential site degradation associated with mountain logging.

Site degradation is obviously unacceptable from the standpoint of a sustained, productive forest. Evident erosion and sedimentation can also devalue land and depress economies, particularly in a region so dependent on tourism, vacation homesites, and retirement homes. This paper presents two case studies of site disturbance from fuelwood harvesting. In one case a rubber-tired cable skidder was used to remove essentially all of the wood from a site. In the second case a small skyline cable yarding system was used to remove only that portion of a stand that was most desirable for firewood.

METHODS

The logging areas were in Floyd and Rabun Counties, Georgia. The Floyd County site is on Ber y College property just northwest of Rome. The Rabun County site is on the Tallulah Ranger District of the Chattahoochee National Forest and lies northeast of Clayton.

The Floyd County site is near a convex ridgetop with slopes ranging from 18 to 22 percent. Before the harvest, the volume in trees 5 inches d.b.h. and larger totalled 27.6 cords per acre. Tree species were hickory (*Carya* spp.), black oak (*Quercus velutina* Lam.), blackgum (*Nyssa sylvatica* Marsh.), chestnut

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oak (Q. prinus L.), shortleaf pine (Pinus echinata Mill.), black cherry (Prunus serotina Ehrh.), white oak (Q. alba L.), black locust (Robinia pseudoacacia L.), yellow-poplar (Liriodendron tulipifera L.), and post oak (Q. stellata Wangenh.). The Total Biomass Cruise Program was used to estimate volumes (Clark and Field 1981). Logging was accomplished with chainsaws and a John Deere 440D[2] rubber-tired cable skidder. This machine was a prototype with an 80 hp engine, heavy duty axle and transmission, and oversized tires It was being tested as a replacement for the JD 440C, which has less horsepower and narrower tires. All trees 5.0 inches d.b.h. and larger were felled and limbed, and main stems were skidded in tree lengths to the landing.

On the Rabun County site slopes range predominately from 21 to 42 percent. The species mix of the original stand included chestnut oak, blackgum, red maple (Acer rubrum L.), white pine (P. strobus L.), scarlet oak (Q. coccinea Muenchh.), sourwood (Oxydendrum arboreum (L.) DC.), northern red oak (Q. rubra L.), hemlock (Tsuga spp.), white oak, yellow-poplar, hickory, shortleaf pine, and black locust. The total stand volume was 19.4 cords per acre. This site was logged with chainsaws and the Bitterroot Miniyarder. This machine is a prototype developed by the Missoula Equipment Development Center, USDA Forest Service, Missoula, Montana (Domenech 1983). The miniyarder is a lightweight, two-drum skyline yarder that can be mounted on a 3/4 ton pickup truck or on a small trailer. It has a live skyline and is powered by an 18-horsepower, 2-cylinder Briggs & Stratton engine. All but a few trees were felled. Logs were bucked prior to yarding and timber removal was limited mostly to merchantable pine logs and hard hardwood fuelwood, except for a few yellow-poplar. Production is presented in a companion paper, "Mountain Logging with the Bitterroot Miniyarder" (Cubbage and Gorse 1984).

Initial conditions on the study sites and volumes removed in logging are shown in Table 1. After logging, areas of soil disturbance were estimated on both sites based on systematic grids of points covering the entire areas. A baseline was established bisecting each area and running up and down to the slope. At 20-foot intervals along the baseline transects were run in both directions perpendicular to the baseline (roughly along the contour) and to the edges of the logging area. Sample points were spaced at 5-foot intervals along the transects resulting in a sample-point density of approximately 1 point per 100 square feet. Each point was then placed in one of the following three disturbance categories:

1. Undisturbed--original duff or litter still covering the mineral soil.

2. Exposed--litter and duff scraped away exposing mineral soil, but with no scarification.

3. Disturbed--mineral soil exposed and scarified or dislocated.

Haul roads and log decks were excluded from the estimates of area disturbed.

RESULTS AND DISCUSSION

Although logging on the two areas was not entirely comparable, it is clear that the miniyarder caused substantially less site disturbance than the cable skidder. The percentages of each of the logged areas in each disturbance class were:

Disturbance class	Cable skidder	Miniyarder
	Percent	
Undisturbed	63	99
Soil exposed	12	1
Soil dislocated	25	0

Operating on a relatively moderate slope, the cable skidding operation exposed mineral soil over 37 percent of the logging area. On 25 percent of the total area the disturbance was severe enough to scarify or dislocate the soil. These results are consistent with findings in a whole-tree harvesting study on slightly more moderate Upper Piedmont slopes where all material 4 inches d.b.h. or larger was removed (McMinn 1983); mineral soil exposure there was 30.3 percent in summer and 34.7 percent with winter logging. The skidder disturbance was distributed fairly uniformly over the logging area. Out of 14 transects of varying length the greatest disturbance was 63 percent and the least was 19 percent. Operators at the Floyd County site had no prior experience with the equipment and appeared to perform a number of unnnecessary maneuvers. Experienced operators would have been more efficient, and might have caused less soil disturbance.

From a practical standpoint the skyline logging system caused no disturbance even though the slope was twice as steep as on the skidder area (Table 1), and the operator had never used a cable system before. Out of a total of 619 sample points 610 were undisturbed, 8 had exposed mineral soil with no scarification or dislocation, and only one point had exposed, scarified soil. As might be expected, the 9 points exhibiting some disturbance were along the two skyline corridors where there were repeated opportunities for disturbance by logs swinging close to the ground. Although only half as much timber was removed as on the Floyd County site, the disturbance was still not proportional to the volume removed. The size distribution of logged material was similar for the two sites (Table 2). Half of the Rabun County site was not logged with the skyline system and will be logged with cable skidders for a more precise comparison. A comprehensive assessment will appear in a future Georgia Forest Research Paper.

ACKNOWLEDGMENT

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Table 1.--Summary of initial conditions and volumes removed for a cable skidder operation and a small skyline yarding system in Floyd and Rabun Counties, Georgia, respectively.

Characteristic	Logging area	
	Floyd County	Rabun County
Logging system	Skidder	Skyline
Slope (percent)	18-22	21-42
Stand volume (cords/acre)		
Pine	4.7	2.8
Hard hardwood	21.0	10.7
Soft hardwood	1.9	5.9
Total	27.6	19.4
Volume removed (cords/acre)		
Pine	4.7	2.8
Hard hardwood	21.0	10.7
Soft hardwood	1.9	0.0
Total	27.6	13.5

Table 2.--Percent diameter distribution for 27.6 cords per acre of material removed by skidding in Floyd County and 13.5 cords per acre of material removed by skyline yarding in Rabun County.

Diameter class	Logging area	
	Floyd County	Rabun County
Inches	*Percent*	
5	14.8	12.3
6	11.1	9.3
7	13.6	16.7
8	14.8	13.2
9	10.5	8.2
10	8.6	13.2
11	8.0	8.6
12	4.9	4.6
13	3.1	5.2
14	3.7	4.1
15	3.1	2.0
16	1.2	2.1
17	1.2	0.0
20	0.6	0.0
22	0.6	0.0
23	0.0	0.5

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SOME ENVIRONMENTAL EFFECTS OF CABLE LOGGING IN THE EASTERN HARDWOODS

by

James H. Patric

ABSTRACT

A wealth of experience points to cable logging as a proven technique of wood products harvest, well suited to protect environmental values in the hardwood forest. Research throughout eastern United States demonstrates minimal effects on soil, water, residual stands, wildlife, and visual appeal. Effects of cable logging are segregated from those attributable to silvicultural treatment. Given competent application, it is concluded that cable systems have great potential to protect environmental values.

SOME ENVIRONMENTAL EFFECTS OF CABLE LOGGING IN THE EASTERN HARDWOODS[1]

James H. Patric[2]

During a recent conversation with Dr. Ernest Gould,[3] he stated that "Erosion of forest soil usually results from logging, not silviculture." Dr. Gould thus distinguished, as one cause of a major environmental ill-effect, between silviculture (i.e. the husbandry of forest trees, usually requiring some form of cutting) and logging (i.e. harvesting the useful parts of cut trees). This distinction seems academic to those who perceive all cutting and other cultural work in the forest as somehow inimical to its environment. To most foresters, the distinction makes sound managerial sense. But regardless of environmental effects, most silvicultural methods provide few choices except to cut, at some stage of growth, those trees needed to satisfy society's manifold needs for wood. As to logging, however, foresters may choose among several techniques. For present purposes, the environmental effects resulting from cable logging will be separated from those attributable to the cutting of trees. This separation is seldom seen; indeed, one wonders if most commentators on environmental effects even appreciate its usefulness.

Let's start by defining some terms, to place all of us on commmon conceptual ground. Eastern hardwoods include those regions between the Atlantic coast and the 100th meridian, where deciduous trees predominate. Environment is the total of circumstances surrounding a group of organisms, pertaining here to deciduous trees and the warm-blooded animals among them--including people. Cable logging is the use of wire rope to harvest all or parts of cut trees. Examples of cable logging technique include the highlead, jammer, and skyline methods. The environmental effects of cable logging described herein presume, not mere ground skidding of logs, but at least partial lift when harvested wood is pulled by wire ropes from stumps to collection points. Such pulling has obvious potential to alter many of the circumstances surrounding forest biota but only those concerning soil, water, residual stands, wildlife, and visual appeal are dealt with here. Other environmental effects on the hardwood forest have received too little attention to attempt substantive description.

1/ This paper was developed from the extensive search of the pertinent literature reported by Patric (1980). A few recent studies are cited which add substantially to that review.

2/ USDA Forest Service, retired.

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SOILS

Soil in the undisturbed wildland forest is a uniquely functioning hydrologic system into which water almost invariably infiltrates as fast as rain falls or as snow melts. Because of this functioning, it follows that (a) water rarely flows across the forest floor and (b) forest streams are nourished by infiltrated water draining into channels through--not across--the forest soil. A firm grasp of this soundly established hydrologic behavior is essential to understanding how forest soil, as well as water, is affected by silvicultural and logging activity.

Sediment production in the wildland forest, ordinarily at rates less than 0.10 ton per acre per year (Patric, et al. 1984) remains near that negligible level because an undisturb forest floor shields the underlying mineral soil from particle dislodgement by raindrop impact. Most of the sediment produced from wildland forest originates as soil eroded, not from the forestfloor, but as detritus scoured from the banks and channels of streams. There, water flows more or less continuously within streambeds which lack the protection of litter or other iorganic cover.

Silvicultural effects. Forest husbandry practices such as herbiciding, pruning, thinning, and even the felling of trees cause little or no change in either the rate or process of water movement within forest soils. Therefore, erosion and sediment production rates ordinarily are unchanged by such practices. The key to sustaining this uniquely functioning hydrologic system is the litter covered forest floor; it is often overlooked that the forester's work in the woods usually bulks the litter cover, not detracting from but adding to its soil protective function. These hydrologic non-effects of silvicultural treatment, virtually unknown to the public, often are disregarded or even misrepresented as some sort of environmental disaster by people who deplore any change from wild-land conditions.

Cable logging effects. Foresters of 50 or more years ago observed negligible erosion following timber harvest on unburned land, pointing instead to deeply worn skid trails as primary sites of objectionable soil loss. That observation has been corroborated repeatedly in watershed management research. Given that 5 to 15% of the managed forest is occupied by skid trails and logging roads (Kochenderfer 1977) and that annual soil losses exceeding 100 tons per acre of road have been measured (Swift 1981), then minimizing the access network is of primary environmental concern. That concern is best met by logging with cable systems; carefully planned harvest by cable logging can reduce the access network about 25 to 50% of that needed to harvest timber using tractors, wheeled skidders, or even animals.

Nonroaded areas of cable-logged land feature less litter disturbance, soil exposure, and surface compaction than is found on land logged by other methods. On West Virginia's Fernow Experimental Forest, for example, only 7% of the forest floor on skyline-logged land was observed as slightly disturbed (A horizon soil exposed) and 3% was severely disturbed (B horizon soil exposed, but 90% was judged undisturbed (no mineral soil exposed, with litter untouched or merely disarranged). There was no measurable increase in the bulk density of B horizon soil, no decrease in rates of infiltration, and no evidence of accelerated erosion on non-roaded land--even on slopes exceeding 70% (Patric and Gorman 1977). Perhaps the most glowing account of non-effect came from Louisiana where, it was professed, not even the most avid environmentalist was concerned about soil exposure on cable logged land (Prater 1973). During logging with a truck-mounted crane, similar minor disturbance of the forest floor accelerated sediment production only slightly above wildland rates (Kochenderfer and Wendel 1980). Moreover, scattered areas of severe disturbance are restored to pre-logging hydrologic performance within a year or two. Litter fall, revegetation, freeze-thaw cycles, and the ever-present actions of soil biota soon combine to obliterate all traces of cable logging on the forest floor.

WATER

Silvicultural effects. As a rule of thumb, each 10% of the basal area cut, per unit area of hardwood trees felled, will increase water yield one inch during the first year after cutting (Bosch and Hewlett 1982). Post-harvest yields decrease as trees regrow, returning to pre-cutting levels within a year or so after light cutting, within 5 to 10 years after clear-cutting. These are on-site increases, measured many times at the mouths of tiny (5 to 50 acres) research watersheds, where they are cut on carefully coordinated schedules. Tree cutting on major river basins (e.g. the Potomac or Kanawha) obviously cannot be so regulated. In that real world of forest management, trees on a myriad of small holdings are cut at the whim of individual owners, in patches widely scattered over time and space. Hypothetically, flow in major river basins will increase after such uncoordinated cutting, but added water yields have thus far proven undetectable at gaging sites downstream from scattered harvest sites. World-wide experience (Bosch and Hewlett 1982) establishes that more than 20% of the basal area must be cut within a year to increase water yield measurably.

Silviculture frequently is suspect as a prime cause of worse flooding--higher, oftener, muddier--than occurs in streams draining uncut forested land. Research repeatedly reports these environmental effects to be minimal. Again, the key is lack of overland flow; as long as storm water drains through the forest soil to streams--not across the surface--cutting can little influence the rate at which it is delivered to channels during storms. This behavior also applies to snowmelt; with infiltration high and cuts scattered, silviculture's influence on melt rates has no effect on flooding in major streams. Increased water yield from cutover land does temporarily extend the extremities of headwater channels upslope, thus exposing a greater length of channel to scour. Increased yield also minutely increases the level and velocity of flow in the channel system. The net effect is slightly more sediment in streams draining cutover land, though it usually remains within the erosion rates ordinarily experienced under wildland forest conditions. All of these minor effects of silviculture on water return to pre-cutting levels as trees regrow.

<u>Cable logging effects.</u> The environmental effects of cable logging on water are woven inextricably into its non-effects on forest soil. Sediment, by far the major pollutant of forest streams, seldom is carried in quantity from cable-logged slopes because the unique hydrologic functioning of forest soil is unaffected, during as well as after wood harvest. The advantages of cable harvest, with respect to logging roads as a source of sediment in forest streams, can hardly be overstated. Roads can be a major sediment source during logging and can remain a source long after all other traces of logging have been obliterated from the non-roaded forest floor. Not only does the cable technique require fewer roads but, because harvested wood is most efficiently yarded uphill, logging roads are advantageously located well upslope from streams, sometimes even along ridge crests. Soil eroded from roads so located is carried no more than a few yards downslope before the conveying water inflitrates the forest floor. Thus, even though some erosion occurs on logging roads, during and after harvest, the sediment so produced usually lodges on the forest floor, seldom carried far enough downslope to enter a stream channel. Because plant nutrients often are carried on sediment, that pollution source too is minimized by cable harvest. Finally, Swank, et al. (1982) described as trivial the effects of high lead logging on stormflow, even on slopes averaging 57%.

RESIDUAL STANDS

<u>Silvicultural effects.</u> Residual trees are crop trees of the future, those which remain after logging. Larger residual trees may be broken, smaller ones crushed when current crop trees are felled.

<u>Cable logging effects.</u> Logging by any technique unavoidably injures some residual trees. Bark on larger residuals may be abraded or torn, smaller ones flattened or uprooted when logs are yarded by cables. Reports of such injuries range the gamut, from ruinous to negligible, but the latter predo minatein reports of modern cable logging. On the Fernow Experimental Forest, for example, such damages were held to low levels, with 51 trees per acre sustaining observable injury, most of it torn bark (Kochenderfer and Wendel 1980). In general, the variation among reports of injury to residual trees leads to the conclusion that it is minimized by careful planning and harvest practices, regardless of the logging technique used.

WILDLIFE

The abundance of animal life in forests is closely related to the energy gradient. In most forests, the availability of solar energy decreases with crown depth until little is available on the forest floor. Animal species are adapted to meet their energy needs at rather specific levels within this distributive range. Deer, for instance, obtain much of their preferred food by browsing from brush and other lower-growing plants, most of which require a fully sunlighted forest floor. Squirrels, on the other hand, den in larger trees and feedheavily on nuts and acorns produced high in their fully illuminated canopies. Birds can be more mobile, seeking various levels of radiation for the food, warmth, and nesting sites preferred by each species.

Silvicultural effects. Because many animals are specialized to rather specific energy strata, numbers and diversity of species tends to be highest where energy distribution is most varied. For that reason, tree cutting--not the method of logging--is critical to wildlife populations. Even the forest openings provided by logging roads tend to offer the energy diversity most beneficial to wildlife. Animal numbers result not so much from what trees were cut or how they were logged, as how many trees were cut and where.

Cable logging effects. Probably it is safe to presume that most of the good and bad effects of timber harvest, on birds and mammals, are attributable to silviculture, that logging by any means has negligible effects. The non-effects of cable logging on soil and water do have important implications to fish in forest streams. Any logging technique that materially increases sediment must injure fish. Because soil erosion and sediment production are essentially unaffected by cable logging, its widest possible use best protects the fish in forest streams.

VISUAL APPEAL

Visual appeal is defined as pleasure derived through the sense of sight. It is strongly conditioned by expectation. It is the expectation of visual pleasure, temporarily lost from wood harvest sites, that disappoints many forest visitors--and gets foresters in trouble. Thus, to urban people seeking beauty in the managed forest, logging appears untidy and destructive, an affront to their visual senses. Rural people tend to view logging more tolerantly, but even they see it a more or less necessary evil, hardly improving the forested landscape. An extreme viewpoint holds that logging so destroys the countryside's beauty that it should be banned altogether.

Silvicultural effects. Because most observers prefer minimal disturbance in forest scenes, logging becomes tantamount to reduced visual appeal. Nevertheless, trees must be cut to provide wood and, as more trees are cut, the greater the perception of disturbance. The unsightly aftermath of logging--stumps, slash, and battered residual trees--can combine with loss of standing trees to create a source of extreme disturbance. These, however, are silvicultural effects, perhaps attributable wholly to the husbandry of trees.

Cable logging effects. As previously noted, cable logging avoids dense networks of unsightly roads, eroding forest soils, sediment in streams, and injury to residual trees. Avoidance of such environmental damages plays a major role in sustaining visual appeal, and here cable logging stands tall. Only balloon and helicopter logging offer greater potential to avoid environmental damages--and thereby to sustain visual appeal--but rare indeed are hardwood stands of sufficient value to return a profit after resort to those costly logging techniques.

Obviously, the visual appeal of the wildland forest cannot be fully sustained, even during cable logging. On the other hand, the scarred and desolate wasteland characteristic of rapacious commercialism is unnecessary. The alternatives relevant to visual appeal are not a choice between the pristine forest or one that is environmentally ruined by logging. Rather, the real choice is among levels of unsightliness. Here, even in cable logging, the key role of skilled and concerned woods personnel can hardly be overstated. Lack of planning, coupled with careless practices, will cause unacceptable environmental damages, regardless of the logging method used given competent and caring workmanship, cable logging has great potential to sustain all of the environmental factors which combine to provide the forest's visual appeal.

CONCLUSION

Cable logging minimizes most of the unwanted effects on the forest environment brought about by meeting society's need for forest products. Even cable systems, however, must be operated proficiently to achieve full potential to protect forest soil, water, residual stands, wildlife, and visual appeal during wood products harvest.

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ECONOMIC IMPLICATIONS OF MANAGING NONPOINT FOREST SOURCES OF WATER POLLUTANTS: A MIDWESTERN PERSPECTIVE

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Abstract: Economic evaluations of six forest practices designed to enhance water quality from 18 timber harvesting operations in the Midwest were carried out. Net revenue reductions ranged from 1.2 percent with redesign of landing and skid trail locations to 26.4 percent with buffer strip requirements. Nine operations were profitable with application of all six practices. Limited production function information hinders such analyses.

The production of quality water from forested land has been subject for especially sharp focus during the past 5-10 years. In large measure this interest stems from 1972 and subsequent amendments of the Federal Water Pollution Control Act which, among other things, required states to define and implement "best management practices" that reduce or prevent nonpoint forest sources of water pollutants. Progress toward such a goal required the forestry community to secure a better understanding of the relationship between management/harvesting practices and the incidence of water pollutants in both physical and economic terms. The latter has proven to be especially challenging (Dykstra and Froehlick 1976, Environmental Protection Agency 1977, Everett and Miller 1975, Gardner 1971, Gillick and Scott 1973, Hickman and Jackson 1979, Kemper and Davis 1976, Miles 1982, Miles and Ellefson 1983, Weible and Ellefson 1980). For example, what is the added cost of undertaking forest practices thought capable of enhancing the flow of quality water? What might be an economically optimum package of forest practices that meet legally imposed water quality standards as well as the revenue objectives of forest landowners and purchasers of timber? And who must incur the added cost of managing to control water pollutants and is there a unique segment of society that reaps the benefits of such investments? Perplexing as questions of this nature may be, they must be addressed if effective laws and programs are to be designed to achieve water quality goals for forested areas.

Economic issues involving management of nonpoint forest sources of water pollutants were addressed by a study of Midwestern timber purchasers during the summer of 1983 (Miles and Ellefson 1983). Procedurally, the study involved identification of forest practices judged capable of enhancing water quality,

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determination of costs and revenues associated with each practice, and marginal analysis of decisions to implement one or more practices. Eighteen timber harvesting operations located in five midwestern states were used as information sources. The study's results are to be interpreted with the following in mind: only costs -- not benefits -- of managing nonpoint, forest sources of pollution were analyzed; economic impact on a single timber purchaser was of major concern -- regional impacts of alternative forest practices were not considered; forest practice outputs other than quality water were not assessed; and the analysis focused on a cost structure representative of publically owned forest land in the Midwest.

SELECTION OF FOREST PRACTICES AND CASE STUDIES

Identification of forest practices considered appropriate to curbing the production of nonpoint source water pollutants -- especially sediment -- involved careful review of various literature sources, evaluation of laws and administrative rules focused on water pollutants from forest sources (Ellefson and Cubbage 1980), and lengthy discussions with forest hydrologists and administrators in public and private service. Such actions lead to selection of the following six practices:

° skid trail and landing design. Application of principals such as crossing streams at right angles, occasionally breaking road grades, constructing skid trails from the "top down," avoiding stream beds and rock outcroppings, slanting skid trails up hills, keeping road grades low, and designing and locating landings prior to harvest (Haussman and Pruett 1978).

° seeding and fertilizer application. Establishment of quickly germinating grasses capable of binding soil, decreasing water velocity and acting as a sediment trap. Such vegetation protects harvested areas until permanent vegetation is established on landings, skid trails, roads and eroding gullies (Sage and Tierson 1975).

° water bars. Installation of earthen bars designed to divert water from skid trails and roads to areas capable of reducing flow rates and enhancing opportunity for infiltration (McClimans et al 1979).

° broad-based dips. Construction of carefully out-sloped sections of road which act as water catchments and drainage channels. Discharge areas must be protected with gravel, grass sod, or heavy concentration of litter or brush. Spacing and construction of broad-based dips is critical to their effectiveness (U.S. Department of Agriculture 1977).

° buffer strips. Leaving unharvested or partially harvested vegetative strips between water areas (e.g., lake, streams) and harvested areas. Designed to trap or filter sediment found in overland flows.

° culverts. Installation and maintenance of culverts so as to curtail concentrations of water on road surfaces and reduce the flow of water over long distances in ditches (Brown 1979 and Winger 1978).

Information to carry-out economic evaluations of quality water producing practices was obtained from records of active timber sales on nine National Forests located in Illinois, Michigan, Minnesota, Missouri and Wisconsin. In all, 18 sales were evaluated -- two from each Forest. Sale selection was predicated on proximity to water (e.g., stream or lake) and on representativeness of the larger forest area in question (e.g., topography, soils, stocking level, forest type, size of sale). A thorough search of active timber sale files was carried out. Once preliminary selections were made, forest hydrologists and sale administrators were consulted to aid in the final selection process. Sale names and their location are as follows:

° Illinois
  Comeenes Pine (Shawnee National Forest)
  Nelson (Shawnee National Forest)

° Michigan
  Dam Balsam (Huron-Manistee National Forest)
  Kennedy Road (Huron-Manistee National Forest)
  Halfaday (Hiawatha National Forest)
  Mormon Creek Hardwood (Hiawatha National Forest)
  Silverlake (Ottawa National Forest)
  Sleepy Creek (Ottawa National Forest)

° Minnesota
  Dunbar Creek (Chippewa National Forest)
  Everton Creek (Chippewa National Forest)
  Leatherleaf (Superior National Forest)
  Big Buck (Superior National Forest)

° Missouri
  Gasconade (Mark Twain National Forest)
  Thompson Cemetery (Mark Twain National Forest)

° Wisconsin
  Johnson Farm Tract (Chequamegon National Forest)
  Mud Lake (Chequamegon National Forest)
  South Seven Mile Lake (Nicolet National Forest)
  West Thunder Mountain (Nicolet National Forest)

REVENUE AND COST CALCULATIONS

Timber sale revenues were determined by calculating the value of harvested timber delivered to the mill. Volumes were separated according to species, diameter and product (e.g., sawtimber, pulpwood). Prices for delivered timber were obtained from various sources including statewide and regional price reporting bulletins. Costs were separated into two major categories, namely, conventional harvesting costs and the cost of alternative practices. The former were reflective of practices "normally" used to harvest timber on the sale in question (e.g., felling, bucking, skidding, hauling). Alternative practice costs reflected additional investments in practices thought capable of enhancing or maintaining the quality of water flowing from a harvested area. Timber sale purchaser's net revenue for a conventional harvest (i.e., without additional water pollution reducing practices) was determined by subtracting conventional harvesting costs from sale revenue. Fourteen of the 18 timber sales had posi-

tive net revenues -- four were judged to be unprofitable. Since calculation of harvest costs can prove especially difficult, the sensitivity of net revenue to a 10 percent increase or decrease in total cost was assessed for each sale. A detailed accounting of cost estimation procedures can be found elsewhere (Miles and Ellefson 1983).

ECONOMIC EVALUATIONS

Financial Impact of Single Practices

Requiring timber purchasers to undertake forest practices deemed necessary to improve the quality of water flowing from forested areas can have a pronounced effect on the net revenue realized by such purchasers. For illustrative purposes, all 18 cases were combined to form a "composite" sale which had the following character:

Practice	Added Cost of Practice (dollars)	Net Revenue (dollars)	Decline in Net Revenue (percent)
Conventional practices	--	124,340	--
Skid Trail and Landing Design	1,556	122,784	1.2
Culverts	6,203	118,137	5.0
Water Bars	9,031	115,309	7.3
Broad-based Dips	10,946	113,394	9.7
Seeding and Fertilizer	19,808	104,532	15.9
Buffer Strips	25,948	98,392	26.4

For the composite sale, revenue reductions due to water quality improving practices ranged from 1.2 percent when landings and skid trails are redesigned to over 26 percent when buffer strips are required. A detailed accounting of financial impacts of added practices on revenue generated by each case study is presented in Table 2. In all cases, additional attention devoted to design of landings and skid trails was the least expensive practice. In nine of the 18 cases evaluated, buffer strips were the most expensive followed at a close second by seeding and the application of fertilizer (eight out of 18).

Cumulative Financial Impact of Practices

Although forest hydrologists do not completely agree on the effectiveness of sediment reducing forest practices, a ranking of practices by effectiveness and an evaluation of their cumulative impact on net revenue could prove of value to forest managers charged with design of "best management practices." Recognizing that effectiveness varies with site and that complex interrelationships occur between practices, application of practices was presumed to occur in the following order: (1) skid trail and landing design, (2) culverts, (3) water bars, (4) buffer strips, (5) seeding and fertilizer, and (6) broadbsed dips. When cumulatively applied in such order, impacts on total harvesting costs and net revenue become substantial -- consider the composite sale (Table 1). Total costs rise in a modest fashion when practices through and including water bars are added (i.e., 1.5 percent); when all five practices are added to conventional practices, harvesting costs rise 6.5 percent. Net revenue impacts, however, are much more pronounced. When all practices are applied, net revenue is reduced by nearly 60 percent.

Adding water-quality enhancing practices in the order stated above has net revenue impacts that vary with the sale in question. Following is the frequency of operations that experience a net revenue equal to or less than zero when additional practices are accumulated:

	Frequency
Timber harvesting operations with zero or less net revenue with conventional practices only:	4
Timber harvesting operations with zero or less net revenue with the addition of:	
Practice 1	0
Practice 1 and 2	0
Practice 1, 2 and 3	1
Practice 1, 2, 3, and 4	3
Practice 1, 2, 3, 4, and 5	4
Practice 1, 2, 3, 4, 5, and 6	5

Excluding the four harvesting operations having less than zero net revenue given application of conventional practices, 14 of the sales have a positive net return when culverts are added and landings and skid trails are redesigned. Thirteen sales maintain economic viability with the addition of such practices plus the installation of water bars. And nine operations could proceed economically if all six additional water quality enhancing practices were adopted. Whether the operators chose to do so would depend on alternative investment opportunities.

SUMMARY AND OBSERVATIONS

Undertaking practices designed to enhance the production of quality water from forested areas implies very real economic consequences for timber harvesting. The magnitude of such impacts varies with the practice in question and the market and financial conditions faced by the timber harvester. Study of 18 public timber sales in five midwestern states suggests that design of skid trails and location of landings may be very cost-effective options for dealing with water quality problems. Certainly such actions are more cost effective than the application of seed and fertilizer to roads and skid trails or the leaving of vegetative buffer strips. At the most, 60 percent of the net revenue generated by a composite sale operation would be eliminated by the application of six water quality enhancing practices. Nine of the sales, however, would be in a position to maintain a positive net revenue under such circumstances.

Economic evaluations of practices designed to reduce or eliminate nonpoint forest sources of water pollutants are clouded by the lack of reliable information which clearly defines benefits -- in economic terms -- of undertaking additional practices. At the crux of the problem is sketchy production function information which links timber harvesting practices to specific levels of water pollutants generated -- or curbed. Information of this sort would go far toward enhancing economic evaluations designed to assess the economic efficiency of alternative practices focused on production of quality water.

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Table 1. Cumulative effect of ranked sediment reducing forest practices on net revenue from 18 timber harvesting operations in the Midwest (composite sale). 1983.

Sediment Reducing Forest Practice	Added Cost of Practice	Total Cost of Harvest	Net Revenue*	Reduction in Net Revenue
	(dollars)	(dollars)	(dollars)	(percent)
Conventional Practices	--	1,137,595	124,340	--
Skid Trail and Landing Design	1,556	1,139,151	122,784	1.3
Culverts	6,203	1,145,354	116,581	6.2
Water Bars	9,031	1,154,385	107,550	13.5
Buffer Strips	25,946	1,180,333	81,602	34.4
Seeding and Fertilizer	19,808	1,200,141	61,794	50.3
Broad-based Dips	10,946	1,211,087	50,848	59.1

* Total revenue = $1,261,935.

Table 2. Cumulative effect of ranked sediment reducing forest practices on net revenue from 18 timber harvesting operations in the Midwest. 1983.

Sediment Reducing Practice	Added Cost of Practice	Cumulative Total Harvest Cost	Cumulative Net Revenue
	(dollars)	(dollars)	(dollars)
CASE 1: Shawnee National Forest, Illinois			
Conventional Practices	--	47,535	-2,262
Skid Trail and Landing Design	89	47,624	-2,351
Culverts	219	47,843	-2,570
Water Bars	587	48,430	-3,157
Buffer Strips	27	48,457	-3,184
Seeding and Fertilizer	762	49,219	-3,946
Broad-based Dips	458	49,677	-4,404
CASE 2: Shawnee National Forest, Illinois			
Conventional Practices	--	25,754	2,688
Skid Trail and Landing Design	10	25,764	2,678
Culverts	567	26,331	2,111
Water Bars	107	26,438	2,004
Buffer Strips	3,696	30,134	-1,692
Seeding and Fertilizer	325	30,459	-2,017
Broad-based Dips	230	30,689	-2,247
CASE 3: Huron-Manistee National Forest, Michigan			
Conventional Practices	--	56,505	16,452
Skid Trail and Landing Design	68	56,573	16,384
Culverts	504	57,077	15,880
Water Bars	1,004	58,081	14,876
Buffer Strips	1,510	59,591	13,366
Seeding and Fertilizer	918	60,509	12,448
Broad-based Dips	756	61,165	11,692
CASE 4: Huron-Manistee National Forest, Michigan			
Conventional Practices	--	176,809	25,263
Skid Trail and Landing Design	238	177,047	25,025
Culverts	--	177,047	25,025
Water Bars	844	177,891	24,181
Buffer Strips	1,698	179,589	22,483
Seeding and Fertilizer	2,148	181,737	20,335
Broad-based Dips	1,095	182,832	19,240

Table 2. (continued)

Sediment Reducing Practice	Added Cost of Practice (dollars)	Cumulative Total Harvest Cost (dollars)	Cumulative Net Revenue (dollars)
CASE 5: Hiawatha National Forest, Michigan			
Conventional Practices	--	14,349	943
Skid Trail and Landing Design	32	14,381	911
Culverts	219	14,600	692
Water Bars	366	14,966	326
Buffer Strips	754	15,720	-428
Seeding and Fertilizer	566	16,286	-994
Broad-based Dips	443	16,729	-1,437
CASE 6: Hiawatha National Forest, Michigan			
Conventional Practices	--	32,397	17,559
Skid Trail and Landing Design	25	32,422	17,534
Culverts	446	32,868	17,088
Water Bars	159	33,027	16,929
Buffer Strips	3,151	36,178	13,776
Seeding and Fertilizer	325	36,503	13,453
Broad-based Dips	192	36,695	13,261
CASE 7: Ottawa National Forest, Michigan			
Conventional Practices	--	32,449	-2,393
Skid Trail and Landing Design	94	32,543	-2,487
Culverts	--	32,543	-2,487
Water Bars	627	33,170	-3,114
Buffer Strips	610	33,780	-3,724
Seeding and Fertilizer	870	34,650	-4,594
Broad-based Dips	399	35,049	-4,993
CASE 8: Ottawa National Forest, Michigan			
Conventional Practices	--	47,065	6,880
Skid Trail and Landing Design	128	47,193	6,752
Culverts	514	47,707	6,238
Water Bars	1,397	49,104	4,841
Buffer Strips	1,292	50,396	3,549
Seeding and Fertilizer	959	51,355	2,590
Broad-based Dips	419	51,774	2,171
CASE 9: Superior National Forest, Minnesota			
Conventional Practices	--	245,827	6,220
Skid Trail and Landing Design	196	246,023	6,024
Culverts	1,000	247,023	5,024
Water Bars	707	247,730	4,317
Buffer Strips	2,178	249,908	2,139
Seeding and Fertilizer	3,923	253,831	-1,784
Broad-based Dips	2,325	256,156	-4,109

Table 2. (continued)

Sediment Reducing Practice	Added Cost of Practice	Cumulative Total Harvest Cost	Cumulative Net Revenue
	(dollars)	(dollars)	(dollars)
CASE 10: Superior National Forest, Minnesota			
Conventional Practices	--	65,055	15,129
Skid Trail and Landing Design	67	65,122	15,062
Culverts	892	66,014	14,170
Water Bars	229	66,243	13,941
Buffer Strips	1,071	67,314	12,870
Seeding and Fertilizer	1,065	68,379	11,805
Broad-based Dips	388	68,767	11,417
CASE 11: Chippewa National Forest, Minnesota			
Conventional Practices	--	41,780	18,312
Skid Trail and Landing Design	44	41,824	18,258
Culverts	194	42,018	18,074
Water Bars	153	42,171	17,921
Buffer Strips	3,358	45,529	14,563
Seeding and Fertilizer	1,301	46,830	13,262
Broad-based Dips	558	47,388	12,704
CASE 12: Chippewa National Forest, Minnesota			
Conventional Practices	--	32,593	5,158
Skid Trail and Landing Design	44	32,637	5,114
Culverts	1,008	33,645	4,106
Water Bars	162	33,807	3,944
Buffer Strips	1,502	35,309	2,442
Seeding and Fertilizer	517	35,826	1,925
Broad-based Dips	388	36,214	1,537
CASE 13: Mark Twain National Forest, Missouri			
Conventional Practices	--	16,482	523
Skid Trail and Landing Design	36	16,518	487
Culverts	194	16,712	293
Water Bars	715	17,427	-422
Buffer Strips	1,338	18,765	-1,760
Seeding and Fertilizer	1,535	20,300	-3,295
Broad-based Dips	1,021	21,321	-4,316
CASE 14: Mark Twain National Forest, Missouri			
Conventional Practices	--	22,292	-130
Skid Trail and Landing Design	51	22,343	-181
Culverts	--	22,343	-181
Water Bars	338	22,681	-519
Buffer Strips	--	22,681	-519
Seeding and Fertilizer	725	23,406	-1,244
Broad-based Dips	348	23,754	-1,592

Table 2. (continued)

Sediment Reducing Practice	Added Cost of Practice (dollars)	Cumulative Total Harvest Cost (dollars)	Cumulative Net Revenue (dollars)
CASE 15: Chequamegon National Forest, Wisconsin			
Conventional Practices	--	52,849	-3,091
Skid Trail and Landing Design	80	52,929	-3,171
Culverts	446	53,375	-3,617
Water Bars	279	53,654	-3,896
Buffer Strips	1,048	54,702	-4,944
Seeding and Fertilizer	548	55,250	-5,492
Broad-based Dips	336	55,586	-5,828
CASE 16: Chequamegon National Forest, Wisconsin			
Conventional Practices	--	21,092	1,212
Skid Trail and Landing Design	32	21,124	1,180
Culverts	--	21,124	1,180
Water Bars	116	21,240	1,064
Buffer Strips	671	21,911	393
Seeding and Fertilizer	371	22,282	22
Broad-based Dips	219	22,501	-197
CASE 17: Nicolet National Forest, Wisconsin			
Conventional Practices	--	12,961	3,874
Skid Trail and Landing Design	42	13,003	3,832
Culverts	--	13,003	3,832
Water Bars	300	13,303	3,532
Buffer Strips	291	13,594	3,241
Seeding and Fertilizer	448	14,042	2,793
Broad-based Dips	152	14,194	2,641
CASE 18: Nicolet National Forest, Wisconsin			
Conventional Practices	--	193,801	12,003
Skid Trail and Landing Design	280	194,081	11,723
Culverts	--	194,081	11,723
Water Bars	937	195,018	10,786
Buffer Strips	1,753	196,771	9,033
Seeding and Fertilizer	2,502	199,273	6,531
Broad-based Dips	1,219	200,492	5,312

COSTS AND RETURNS FROM MECHANIZED FUELWOOD THINNING OPERATIONS

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ABSTRACT

Is the surplus of West Virginia timber in the form of cleanings and thinnings readily available to be economically harvested as fuelwood? A study of six hypothetical fuelwood production operations with three marketing options was conducted at the West Virginia University Forest using a three-man crew and a rubber-tired skidder in thinning a 50 year old stand of mixed hardwoods. Given the production costs and market forces in the Morgantown area, fuelwood production by itself could not be considered a viable economic opportunity. Forest owners, both private and public, would have to assign considerable value to the silvicultural effect of fuelwood thinnings in order to make profitable timber stand improvements by means of fuelwood cutting.

INTRODUCTION

A recent study estimates that domestic fuelwood consumption in West Virginia during the 1981-82 heating season was slightly more than half a million standard cords (Boguszewski, et. al., 1984). This level of consumption was about 2 2/3 times the level of five years earlier. The same study estimates that domestic fuelwood consumption in West Virginia in 1991-92 may be as high as 900,000 cords and that fuelwood may, at that time, be the major forest product in the state in terms of wood volume.

In spite of these high estimates of future consumption, it seems probable that West Virginia forests have the physical and biological potential of meeting these needs without a reduction in the supply of other forest products (Sarles, 1979). There is plenty of wood available in the form of right-of-way clearings, cleanings, and thinnings to supply all fuelwood needs. But a question remains as to whether this material is economically available as fuelwood. Can fuelwood in the form of rough and

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rotten material or thinnings, scattered as it is more or less evenly throughout our hardwood forests, with relatively low volumes per acre, be harvested at a profit?

In a recent study designed to help answer this question, Wartluft and Sarles (1982) found that fuelwood harvesting in mountainous terrain appeared to be a losing proposition because of high production costs and lack of local markets.

OBJECTIVES

The objective of the present study was to determine whether fuelwood resulting from a mechanized thinning could be produced and marketed on a state forest so that product price would cover the cost of production.

PROCEDURE

The study was conducted on Coopers Rock State Forest, about 10 miles northeast of Morgantown, W.V. The thinning took place on three acres of a 53-year old stand of cove hardwoods with a site index of 80. The slope percentage varied from nearly level to 40 percent. About 45 cords of wood were marked for removal, reducing the basal area by 35 percent.

A three-person crew was used in the harvesting, and a two-person crew in the loading and hauling activities. Machinery included a 70 horsepower JD440-B rubber-tired skidder, two Stihl .032 chainsaws and an International half-ton pick-up truck capable of hauling a half-cord of fuelwood.

For purposes of the time and cost study, the operation was separated into eight activities,[1/] as follows:

1. Marking trees for removal as fuelwood
2. Felling, limbing and topping marked trees
3. Skidding downed trees from the forest to the landing
4. Bucking logs into woodstove lengths (16 to 20 inches)
5. Stacking bucked wood at the landing
6. Loading stacked wood onto the delivery truck
7. Hauling wood to the consumer
8. Unloading and stacking wood at the consumer's residence

Three marketing options were investigated in the study.

Option 1 - Sell tree-length logs at the landing. Costs incurred were those of activities 1-3. Selling price was $30 per cord.

[1/] Data for activities 6 through 8 were taken from a related cost study conducted earlier and previously published (White and Wilson, 1982).

Option 2 - Sell bucked fuelwood at the landing. Costs incurred were those of activities 1-5. Selling price was $60 per cord.

Option 3 - Deliver bucked fuelwood to consumers' residences in the Morgantown area. Costs incurred were those of activities 1-8. Selling price was $80 per cord.

The cost analysis was performed using two different wage rates and three equipment rates based on the age of the skidder and the truck. The two wages rates were $3.50 per hour (low rate) and $5.00 per hour (medium rate). Fringe benefits of 33 percent were added making labor costs $4.66 per worker-hour and $6.65 per worker-hour, respectively.

From the two alternative labor rates and three alternative machine rates a total of six hypothetical operations were established as follows:

Operation A - new equipment, medium wage rate
Operation B - new equipment, low wage rate
Operation C - used equipment (4 years), medium wage rate
Operation D - used equipment (4 years), low wage rate
Operation E - used equipment (7 years), medium wage rate
Operation F - used equipment (7 years), low wage rate

Equipment costs for the skidder and truck were calculated using equations develoepd by Miyata (1980) for ages 1, 4, and 7 years. Operating costs took into account the higher cost of maintenance and repairs resulting from the use of older equipment. Chainsaw costs were held constant for all operations; it was assumed that chainsaws would be replaced every two years.

Table 1 shows the dollar-per-hour cost of labor and equipment for each of the six operations.

Table 1. Cost of labor and equipment for each hypothetical operation.

Operation	Age of Equipment	Labor Cost	Equipment Costs			
			Skidder	Chainsaw	Truck	Total
		------------- Dollars per hour ------------				
A	New	6.65	24.30	1.30	7.60	32.20
B	New	4.66	24.30	1.30	7.60	33.20
C	4 yrs.	6.65	14.05	1.30	7.69	23.04
D	4 yrs.	4.66	14.05	1.30	7.69	23.04
E	7 yrs.	6.65	16.18	1.30	6.69	24.17
F	7 yrs.	4.66	16.18	1.30	6.69	24.17

RESULTS

These hourly rates were applied to the results of the time study in order to obtain the total cost per cord for each of the 18 combinations (Table 2).

Table 2. Cost of producing fuelwood by operation and marketing option.

Marketing Option	Cost of producing fuelwood Operation A	B	C	D	E	F
	Dollars per cord					
1. Tree-length logs sold at landing	63.30	54.90	49.86	41.47	52.65	44.26
2. Bucked fuelwood sold at landing	81.64	68.33	68.20	54.90	70.99	57.69
3. Bucked fuelwood delivered to buyer's residence	165.63	136.57	152.55	123.51	151.22	122.17

Comparing the price per cord for each of the marketing options results in a net revenue or net loss for each of the 18 combinations (Table 3).

Table 3. Net revenue (loss) per cord of fuelwood for six hypothetical production operations and three marketing options.

Marketing Option	Net revenue (loss) for each operation A	B	C	D	E	F
	Dollars per cord					
1. Tree-length logs sold at landing for $30/cord	(33.30)	(24.90)	(19.86)	(11.47)	(22.65)	(14.26)
2. Bucked fuelwood sold at landing for $60/cord	(21.64)	(8.33)	(8.20)	5.10	(10.99)	2.31
3. Bucked fuelwood delivered to the buyer's residence for $80/cord	(85.63)	(56.57)	(72.55)	(43.51)	(71.22)	(42.17)

The figures in Table 3 show that none of the operations in Marketing Option 1 (tree-length logs sold at landing) or Marketing Option 3 (bucked wood delivered to the buyer) resulted in a

positive net revenue. The loss per cord for Option 3 was especially high. Only in Marketing Option 2 (bucked fuelwood sold at landing) was there a positive net revenue and then only for Operation D (4 year old equipment, low wage) and F (7 year old equipment, low wage).

Given the production costs encountered in this study and the market forces at work in the Morgantown area at the time of the study, one can draw the following conclusions:

First, fuelwood production is an activity of doubtful profitability in Appalachian hardwood stands, even if the stumpage has zero cost. In other words, fuelwood stumpage is likely to have a negative value.

Second, the best opportunity for profitability appears to be in selling bucked fuelwood at the woods landing. Consumers, many of whom own pick-up trucks, are willing to discount the value of their own time and cost in hauling to the extent that a producer can't meet his costs in delivering wood to the user. On the other hand, consumers are willing to pay a premium for having logs bucked to fuelwood size at the landing, so this phase of the production process (the bucking) is the most profitable for the producer.

Third, only those operations that pay minimum wages and have very low equipment costs can hope to make a profit, even when the most profitable marketing option is used. No fuelwood operation is likely to be profitable if it must bear the cost of amortizing a new piece of harvesting machinery of a conventional type.

Fourth, given the supply/demand relationships for fuelwood in the area, and the willingness of fuelwood consumers to discount the value of their own time and efforts in obtaining fuelwood, fuelwood production in and of itself cannot be considered a viable economic opportunity at the present time.

Finally, forest owners, including public owners, who wish to use fuelwood sales as a means of financing timber stand improvement work, will have to assign considerable value to the effect of thinnings in order to make the TSI work profitable.

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LOGGING DAMAGE ASSOCIATED WITH THINNING CENTRAL APPALACHIAN HARDWOOD STANDS WITH A WHEELED SKIDDER

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ABSTRACT

In north central West Virginia, unmanaged 53-year-old, mixed oak-cove hardwood stands were thinned to 75, 60, and 45 percent residual stocking. Cut trees were skidded tree-length with a rubber-tired skidder. Logging destroyed or severely bent 26, 29, and 34 percent of the unmarked stems in the 75, 60, and 45 percent stocking plots, respectively. Because 94 percent of the destroyed and bent trees were less than 5.0 inches dbh, the effect on basal area and residual stocking was slight. Damage reduced the stocking by 6, 4, and 5 percent in the 75, 60, and 45 percent stocking plots, respectively. All plots combined, 14 percent of the residual stems sustained broken tops, which affected only 3 percent of the residual basal area. Less than 10 percent of the residual stems received wounds that resulted in exposed sapwood. Study results indicate that marking guidelines in the merchantable portion of the stand do not need to be adjusted to account for logging damage.

INTRODUCTION

Intensive forest management in hardwood stands involves a series of partial cuts in both even-aged and uneven-aged systems. These partial cuts damage some residual trees during the logging operation. Damage may include destruction of a potential crop tree, or it may be limited to broken branches or a skinned stem. An important question in thinning even-aged stands is: Should the marked cut be adjusted to account for logging damage to residual stems? We studied the effect of logging damage on residual stand density in mixed oak-cove hardwood stands thinned to three levels of residual stocking with a rubber-tired skidder.

Intermediate cuttings in hardwood stands can be controlled by quantitative stocking guides developed for major eastern forest types. The current recommendation for thinning oak stands is a residual stand density of about 60 percent of full stocking (Gingrich 1967). However, some studies indicate that additional stand growth may be achieved at densities lower than the recommended level (Leak 1981; Dale 1972). As part of a study to test the applicability of the upland oaks stocking guide (Gingrich 1967) in West Virginia, plots were thinned to 75, 60, and 45 percent residual stocking. In addition to growth and yield information, the plots provided data on logging damage associated with each level of thinning.

THE STUDY AREA

The study area was located on the West Virginia University Forest in north central West Virginia. Thinning treatments were applied in the mixed oak-cove hardwood type on generally northeast facing slopes. The stand was

53 years old with a site index of 70 for oak at the time the treatments were applied. The terrain was gentle rolling hills with slopes generally less than 10 percent.

For trees at least 1.0 inch dbh, the stands averaged 431 trees per acre with a basal area of 145 ft^2 per acre, a cubic-foot volume of 3,125 ft^3 for trees at least 5.0 inches dbh, and a board-foot volume (International) of 13,951 fbm per acre for trees at least 11.0 inches dbh. The stands were 129 percent stocked prior to treatment (Gingrich 1967).

DATA

Fifteen 3-acre plots, 5 at each thinning level, were included in this portion of the study. Within each 3-acre plot, a 1/2-acre observation plot was installed. After the 3-acre plots were marked for thinning, all residual trees at least 1.0 inch dbh on the observation plots were permanently identified. Each tree was carefully examined for wounds resulting from natural causes before logging. Species, diameter, crown class, and condition remarks also were recorded before logging.

The plots were logged by a commercial crew using chain saws and a rubber-tired skidder. Crew size varied from 2 to 3 men, depending on the circumstances. Merchantable logs were skidded tree-length to the decking area. Trees 3.6 inches dbh and larger were marked, but those less than 7.0 inches dbh were cut and left in the woods. Up to 4 chokers were used per hitch and the skidder was permitted to run throughout the plot. Trees from one 3-acre plot were not skidded through other plots. Felling and skidding started at the back of each plot and proceeded toward the main skid road or deck. Trees were directionally felled whenever possible, though the terrain and stand density made this difficult in some locations. The logging operations were done in the spring when the bark was slipping and logging damage to residual trees could be expected to be greatest. After logging, each residual tree on the measurement plots was carefully examined for four logging injuries: 1) completely destroyed; 2) bent or severely leaning; 3) exposed sapwood; 4) broken tops. The length and width of each sapwood-exposed wound were measured.

Data from the 1/2-acre measurement plots provided information relating to logging damage in only a portion of the residual stand. Because the logging contractor was not permitted to locate skid roads near the growth plots, the data do not represent the type of damage sustained along skid roads. In Appalachia, skid roads, haul roads, and landings occupy about 10 percent of the area logged with wheeled skidders (Kochenderfer 1977). Probably another 5 percent of the total area logged sustains damage that is not represented by the 1/2-acre plot data. As a result, the logging damage reported here represents the area between roads and landings, roughly 85 percent of the total area logged.

RESULTS

Two types of damage, destroyed trees and bent or severely leaning trees, reduced the number of residual trees and lowered the residual stand stocking below the desired level. In the following discussions, these types of damage are expressed as a percentage of the unmarked portion of the stand. Conversely, damage involving exposed sapwood and broken tops affected only the quality of the residual trees and did not affect stand stocking. These types of damage are expressed as

a percentage of the net residual stand--the unmarked stand minus destroyed and bent or severely leaning stems.

Destroyed

For the 75, 60, and 45 percent residual stocking plots, 14, 20, and 27 percent, respectively, of the unmarked trees were destroyed by logging. Because most of the destroyed trees (94 percent) were less than 5.0 inches dbh, residual basal area was not seriously reduced. Only 4, 2, and 5 percent of the unmarked basal area was destroyed by logging in the 75, 60, and 45 percent stocking plots, respectively (Tables 1, 2, 3). One sawtimber-size tree per acre was destroyed in each of the 75 and 45 percent stocking plots. No sawtimber-size trees were destroyed in the 60 percent stocking plots.

Bent or Severely Leaning

For the 75, 60, and 45 percent stocking levels, a total of 41, 22, and 15 stems per acre, respectively, were bent or left leaning after logging. Ninety-two percent of these trees were less than 5.0 inches dbh. This form of damage amounted to 9 percent of the unmarked stems and about 2 percent of the unmarked basal area (Tables 1, 2, 3). Although this type of injury did not kill the trees, damage of this type associated with snow and ice often results in dead trees in the near future.

Effect on Residual Stocking

The plots were marked according to the stocking guide for upland oaks (Gingrich 1967) without making allowances for logging damage to the residual stand. In computing residual stocking, trees that were bent and trees that were destroyed were not considered part of the residual stand. As a result of logging damage, actual residual stand stocking was 69, 56, and 40 percent in the 75, 60, and 45 percent residual stocking plots, respectively (Tables 1, 2, 3).

Some of the trees that survived the logging operation suffered skinned stems or broken tops. These injuries did not affect residual stand stocking.

Exposed Sapwood

In the 75 percent residual stocking plots, 5 percent of the residual stems and 3 percent of the residual basal area had exposed sapwood damage (Table 1). In the 60 percent residual stocking plots, 9 percent of the residual stems and 11 percent of the residual basal area had exposed sapwood (Table 2). Sapwood damage was most severe in the 45 percent residual stocking plots. Eighteen percent of the residual stems and 16 percent of the residual basal area had exposed sapwood in the heavy thinning treatment (Table 3). Thus, exposed sapwood was directly related to intensity of thinning--as the number of stems and basal area removed increased, a greater percentage of the residual stand suffered exposed sapwood wounds.

An important factor in sapwood damage is the size of the tree suffering the wound. In this study, the percentage of residual trees with exposed sapwood increased with heavier thinning. However, the distribution of sapwood damage among size classes remained about the same in each treatment. For all treatments combined, about 53 percent of the wounded trees were less than 5.0 inches dbh

Table 1. Summary of logging damage in plots thinned to 75 percent residual stocking

Item	Number of stems				Basal area, ft^2/acre				Cubic-foot volume			Board foot volume (Int)	Percent stocking
	1.0-4.9	5.0-10.9	11.0+	Total	1.0-4.9	5.0-10.9	11.0+	Total	5.0-10.9	11.0+	Total	11.0+	
INITIAL STAND													
Initial	267	149	68	484	9.2	53.4	74.1	136.7	1,013	1,891	2,904	10,972	123
Marked cut	25	84	19	128	2.5	28.9	23.1	54.5	545	598	1,143	3,763	
Unmarked stand	242	65	49	356	6.7	24.5	51.0	82.2	468	1,293	1,761	7,209	75
LOGGING DAMAGE													
Bent or leaning	39	2	0	41	1.1	0.6	0	1.7	8	0	8	0	
Destroyed	46	3	1	50	1.3	0.7	0.9	2.9	14	22	36	83	
Percent	35	8	2	26	36.0	5.0	2.0	6.0	5	2	2	1	
Net residual[2]	157	60	48	265	4.3	23.2	50.1	77.6	446	1,271	1,717	7,126	69
Exposed sapwood	7	5	1	13	0.3	1.6	0.7	2.6	30	18	48	74	
Percent[3]	4	8	2	5	7.0	7.0	1.0	3.0	7	1	3	1	
Broken top	28	1	0	29	0.7	0.4	0	1.1	2	0	2	0	
Percent[3]	18	2	0	11	16.0	2.0	0	1.0	0	0	0	0	

[1]Percent of unmarked stand. [2]Net residual=unmarked stand-bent or leaning-destroyed. [3]Percent of net residual stand.

Table 2. Summary of logging damage in plots thinned to 60 percent residual stocking.

Item	Number of stems				Basal area, ft^2/acre				Cubic-foot volume			Board foot volume (Int)	Percent stocking
	1.0-4.9	5.0-10.9	11.0+	Total	1.0-4.9	5.0-10.9	11.0+	Total	5.0-10.9	11.0+	Total	11.0+	
INITIAL STAND													
Initial	18	154	81	423	6.9	51.8	93.9	152.6	925	2,378	3,303	15,625	138
Marked cut	24	107	40	171	2.3	33.4	49.3	85.0	582	1,262	1,864	8,391	
Unmarked stand	164	47	41	252	4.6	18.4	44.6	67.6	343	1,116	1,439	7,234	60
LOGGING DAMAGE													
Bent or leaning	20	2	0	22	0.5	0.9	0	1.4	15	0	75	0	
Destroyed	48	2	0	50	1.1	0.4	0	1.5	6	0	6	0	
Percent[1]	41	9	0	29	35.0	7.0	0	4.0	6	0	6	0	
Net residual[2]	96	43	41	180	3.0	17.1	44.6	64.7	322	1,116	1,358	7,234	56
Exposed sapwood	7	6	4	17	0.2	2.4	4.2	6.8	46	113	149	512	
Percent[3]	7	14	10	9	7.0	14.0	9.0	11.0	14	10	11	7	
Broken top	19	1	1	21	0.5	0.2	1.2	1.9	4	29	33	244	
Percent[3]	20	2	2	12	17.0	1.0	3.0	3.0	1	3	2	3	

[1]Percent of unmarked stand. [2]Net residual = unmarked stand-bent or leaning-destroyed. [3]Percent of net residual stand.

Table 3. Summary of logging damage in plots thinned to 45 percent residual stocking.

Item	Number of stems				Basal area, ft^2/acre				Cubic-foot volume			Board foot volume (Int)	Percent stocking
	1.0-4.9	5.0-10.9	11.0+	Total	1.0-4.9	5.0-10.9	11.0+	Total	5.0-10.9	11.0+	Total	11.0+	
INITIAL STAND													
Initial	179	130	78	387	7.0	43.7	93.9	144.6	782	2,387	3,169	15,255	126
Market cut	32	93	48	173	3.3	28.9	62.8	95.0	507	1,617	2,124	10,792	
Unmarked stand	147	37	30	214	3.7	14.8	31.1	49.6	275	770	1,045	4,463	45
LOGGING DAMAGE													
Bent or leaning	13	2	0	15	0.3	0.8	0.2	1.3	14	6	20	26	
Destroyed	54	2	1	57	1.3	0.6	0.7	2.6	10	18	28	91	
Percent[1]	46	11	3	34	43.0	9.0	3.0	8.0	9	3	5	3	
Net residual[2]	80	33	29	142	2.1	13.4	30.2	45.7	251	746	997	4,346	40
Exposed sapwood	15	4	6	25	0.4	1.7	5.4	7.5	31	129	160	589	
Percent[3]	19	12	21	18	19.0	13.0	18.0	16.0	12	17	16	14	
Broken top	27	3	0	30	0.9	0.9	0	1.8	17	0	17	0	
Percent[3]	34	9	0	21	43.0	7.0	0	4.0	7	0	2	0	

[1]Percent of unmarked stand. [2]Net residual=unmarked stand-bent or leaning-destroyed. [3]Percent of net residual stand.

and 80 percent were less than 11.0 inches dbh.

Broken Tops

A few residual trees suffered broken tops during logging (Tables 1, 2, 3). The most damage occurred in the heavily thinned plots (45 percent residual stocking), where 21 percent of the residual trees suffered broken tops. In the 60 and 75 percent residual plots, 12 and 11 percent of residual trees, respectively, suffered broken tops. Nearly all trees (93 percent) with this type of injury were less than 5.0 inches dbh. As a result, a very small portion of the residual basal area was affected by top damage.

Injuries to Potential Crop Trees

Trees in a dominant or codominant position after thinning are the most likely crop trees of future harvests. The stand was marked to favor these trees so that growth would be concentrated on the best trees in the stand--a major objective of thinning. We examined dominants and codominants to determine the extent of logging damage to the crop trees of the future.

At the 60 percent residual stocking level, the current recommended thinning treatment, 68 dominant and codominant stems per acre were left in the stand. One tree per acre was severely bent and had to be eliminated from the net residual stand. Of the remaining 67 dominant and codominant trees per acre, 7 trees (10 percent) suffered exposed sapwood wounds. Only three of the wounded crop trees (4 percent) suffered severe wounds greater than 100 in^2 of exposed sapwood.

At the 45 percent residual stocking level, 57 dominant and codominant stems per acre were left in the stand. One tree per acre was destroyed, and two trees per acre were severely bent and eliminated from the net residual stand. Of the remaining 54 dominant and codominant trees per acre, 15 trees (28 percent) suffered exposed sapwood wounds. Only one of the wounded crop trees (2 percent) suffered severe wounds greater than 100 in^2 of exposed sapwood.

DISCUSSION

The results of this study are similar to other studies of logging damage in upland hardwood stands. In partial cuts, when using a rubber-tired skidder or crawler tractor with a rubber-tired arch and skidding tree-length, logging damage eliminated less than 10 percent of the residual basal area in the stand. Moreover, this damage was concentrated in the lower diameter classes (Weitzman and Holcomb 1952; Herrick and Deitschman 1956; Nyland and Gabriel 1972). In our study, damage and destruction of residual stems reduced stocking by 6, 4, and 5 percent in the 75, 60, and 45 percent stocking treatments, respectively. Because of the losses occurred in trees less than 5.0 inches dbh, competition for light among dominant, codominant, and intermediate trees was not influenced by logging damage.

Size of exposed sapwood wounds is an important factor in assessing logging damage. Hesterberg (1957) studied wounds on sugar maple and concluded that the amount of cull loss from a logging injury depends on the width of the wound and the length of time following the injury. His study showed that about 10 percent of the gross volume in wounded trees was degraded both 10 and 20 years after the injury occurred.

Apparently, narrow wounds are covered with callous tissue within the first 10 years, and no further degrading occurs in the next 10 years. Volume losses, however, were higher on trees with 20-year-old wounds. For example, 4-inch-wide scars caused about 3 board feet of cull after 10 years and 11 board feet of cull after 20 years (Hesterberg 1957). Wounds 8 inches wide can lead to cull deductions of 20 and 35 board feet 10 and 20 years, respectively, after the injury occurs. As cull deductions increase with time, further degrading will occur, and value losses will increase rapidly.

In this study, wounds on dominant and codominant stems averaged 5.5 inches wide. However, only 10 percent of the dominant and codominant stems suffered any wound at all. The other 90 percent were not damaged. In other words, it seems that most of the sapwood wounds on potential crop trees are small enough to heal with little danger of sapwood decay. Also, many of the trees with large sapwood exposed wounds can be removed in future thinnings before serious cull losses occur.

CONCLUSIONS

- Logging damage associated with the rubber-tired skidder was concentrated in trees less than 5.0 inches dbh.

- At the 60 percent stocking level, the current recommended thinning treatment, logging damage reduced residual stocking by only 4 percent.

  - Damage to residual dominant and codominant crop trees was not severe. Only one tree per acre (1.5 percent) was destroyed.

  - Ten percent of the residual dominant and codominant crop trees suffered sapwood-exposed wounds. Only 4 percent suffered wounds larger than 100 in^2.

RECOMMENDATIONS

- Marking guidelines in trees over 5.0 inches dbh do not need to be adjusted to account for logging damage.

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A SILVICULTURAL EVALUATION OF CABLE YARDING FOR PARTIAL CUTS

by

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ABSTRACT

A literature survey related to cable yarding in partially-cut stands indicates that damages to residual trees, understory reproduction, soil and water quality from well-planned cable operations is comparable to, or less, than that from rubber-tired skidder or tractor logging. In even-aged management damage to small trees and the understory is not as critical as in uneven-aged management. Even in uneven-aged management, however, the younger trees (growing stock) can be adequately protected if damage is minimized through careful planning of the yarding operation and proper training of loggers.

A SILVICULTURAL EVALUATION OF CABLE YARDING FOR PARTIAL CUTS

Kenneth L. Carvell*

I have recently surveyed the literature and examined several logging areas to evaluate the place of cable yarding for partial cuttings in Appalachian hardwood stands with particular emphasis on silvicultural considerations related to northern hardwood types. At present most Appalachian logging contractors use rubber-tired skidders or a tractor. Many feel that cable yarding has a definite place in harvesting stands in mountainous terrain. Some of my specific interests in this survey were to determine whether cable yarding in partially-cut stands resulted in more damage to residual trees than would normally be expected from tractors or skidders. I was also interested in the types of damage to residuals, if these serve as serious infection courts for fungi or insects, and also in root damage, erosion and soil compaction.

Why this renewed interest in cable systems? Since the major eye-sore from logging operations, and a primary factor in water pollution, is the amount of disturbed soil from skidding and logging roads, cable yarding offers a definite advantage over tractors or skidders. At the Fernow Experimental Forest in West Virginia they found that one mile of road was required to log about 20 acres with tractors. When cable systems such as jammers were used, one mile of bulldozed road was needed to log 31 acres; skylines allow even greater acreages per mile of road (Kochenderfer and Wendel 1978).

In addition cables can log over topography that is too steep or rocky for tractors or skidders. Cable settings can be so laid out that logs are lifted high above streams. Furthermore it is possible to erect intermediate supports which raise the cable and load so that convex slopes can be harvested and logs brought to decks on the ridges above (Kochenderfer and Wendel 1978, Biller 1979). Intermediate supports are often needed whenever corridors are over 500 feet long. Spacing between corridors varies from 150 to 300 feet, and corridor length can be 600 to 900 feet, or with running skylines up to 2,000 feet (Burke 1975).

PARTIAL CUTTINGS VERSUS CLEARCUTTING

Until recently most cable yarding was done in clearcutting operations. Cable yarding involves moving large loads of logs, skidded over the ground, with one end dragging on the soil or litter, to the log deck or to the carriage, where they are hoisted above the ground. When logs are being winched, skidded or yarded, their movement is difficult to control due to slope. In the past decade, however, there has been increasing interest in the economics and silvicultural feasibility of using cable yarding for partial cuts.

Partial cuttings include thinnings, improvement cuttings, selection cuttings, and the seed cut of a two-cut shelterwood. From the silvicultural standpoint

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major considerations are: what kinds of bole damages occur to residual trees, how serious are these damages; what tree species are most susceptible to wounding; do wounds close quickly or provide sources of decay and discoloration; how much damage occurs to the understory; is breakage of roots and branches a problem; and the amount of soil erosion and compaction?

Since tractor logging, or rubber-tired skidders, are so commonplace, and since any type of yarding or skidding results in some damage to residual trees, most cable-yarding studies have compared damage to residuals from cable systems to that from tractors or skidders.

DAMAGE TO TREE BOLES AND ROOTS

Most decay and defect in trees originate in and spread from some kind of wound, and the impact of these wounds is likely to increase with increasing time to final harvest (Shigo and Larson 1969). On the Fernow Experimental Forest in 1974 partial cuts were made using a Urus skyline with a 15-foot wide corridor. Before yarding, trees were bucked into 16- to 32-foot lengths. Wounding of trees was no greater than where logs had been removed by tractors or skidders. Only 7 of 40 injured trees were completely eliminated, and most of these were stems less than 6 inches dbh that were ridden down or broken (Northeastern Forest Experiment Station 1974).

In later studies on the Fernow using a truck-mounted crane, a jammer, there were 512 residual trees per acre larger than 1 inch dbh. Of these less than 1 percent had abrasion-type wounds or root damage, 9 percent were skinned, and 1 percent were destroyed (Kochenderfer and Wendel 1980).

Bark abrasions do not usually cause significant permanent damage. Scuffing and gouge-type wounds, where the sapwood, cambium and possibly the heartwood, are exposed, however, are a common injury and of greater concern. Deterioration from scuffing wounds is related to wound width (at least in sugar maple), since width affects wound closure time. Wounds less than 4 inches wide healed in as little as 2 to 4 years. The longer a wound remains open, the more discoloration and rot will be present. Discoloration and rot do not continue to increase after wound closure, since the new cells over these wounds compartmentalize the decay (Hesterberg 1957, Jorgensen 1962, Shigo 1966).

Hesterberg (1957) noted that discoloration and rot from exposed sapwood spread inward only short distances over a 10-year period, but in 20 years became very significant in open wound areas. Philippine studies of logging wounds showed that decay in heartwood advanced much more rapidly on moist sites than on intermediate, and rate of spread on dry sites was only one-seventh that on wet areas (Eusebio 1977).

Benson and Gonsior (1981) report that 23 percent of the leave trees, western larch and Douglas-fir, in a two-cut shelterwood were killed by skyline logging, and 66 percent were damaged to some extent, but only 10 percent had moderate to serious damage. In units where loggers attempted to protect understory trees, about 40 percent were killed or damaged, compared to 76 percent on other areas.

Gibson and Biller (1975) report on damage to a selectively-cut stand on the Fernow where a Urus skyline was used. On this area 40 residual trees, or 9 per acre, received some injury from yarding. Twenty-three percent of the injuries were bark abrasions, 60 percent were skinned bark, 12 percent broken

stems, and 5 percent bent stems. No root damage was found.

Aho et al. (1983) report on damage in thinned white and red fir, Douglas-fir and ponderosa pine mixtures in northern California where rubber-tired skidders were used. Significant decay losses were associated with logging wounds, particularly injury to the lower bole. In five conventionally-thinned stands 22 to 50 percent of the residual trees were wounded. In stands thinned using techniques that were designed to reduce logging and skidding injuries, damage to residuals was substantially reduced, ranging from 5 to 14 percent, emphasizing that care in felling and yarding is extremely important. Basal wounds were more common than bole wounds, followed by crown wounds.

In Vermont studies using a rubber-tired skidder, 21 percent of the remaining trees in a shelterwood area were wounded, while in a selection area 27 percent were wounded. Sixty-two percent of the trees along skid trails had wounds. In the zone 10 feet back from skid trails only 20 percent of the trees were damaged (Hannah et al. 1981). Similarly, Nyland et al. (1977) in New York studies using skidders found that 35 percent of the remaining trees were injured when the stand was marked for cutting, but when the loggers selected the trees to cut 44 percent were injured.

Skyline yarding in Siberian coniferous stands destroyed only 8 to 17 percent of the understory trees. This was far less than were eliminated by ground yarding (Gass 1962).

Naumenko and Barannikov (1959) in Siberian studies compared damage from tractors, skylines, winches and ground lines. There was less damage to understory spruce and fir when skylines were used in winter logging. Preen et al. (1977) reported that in both young and old European beech stands felling and skidding damaged and average wound size were much greater from summer logging than winter logging due to the bark being much more firmly attached in winter.

Damage to surface roots is greatest from tractor skidding. Olsen (1952) found that frozen soil, and snow and ice cover, reduced the impact of repeated use of tractor roads on the surface roots of trees.

Wendel and Kochenderfer (1978) observed that most of the damage from skyline yarding using a Urus was to roots on only one side of the tree. This was caused by logs being yarded laterally to the skyline. Examination of these trees 6 months later showed no permanent damage and no vigor decline. Birches and other shallow-rooted trees were most subject to damage of surface soil.

CONTROLLING BOLE DAMAGE

Most studies of cable yarding in partially-cut stands suggest methods and procedures that reduce bole injuries. Careful felling is essential, particularly on steep terrain (Fieber et al. 1982). To alleviate the problem of residuals being used as turning points for logs, trees should be felled in a herring-bone pattern on either side of the corridor at a 30° angle to the corridor, not criss-cross, and the carriage stopped somewhat above their location (Löffler et al. 1972). This avoids logs being skidded with the front end elevated, parallel to the contour, causing the far end to shift down hill, a source of much bole damage. When logs hang up, loggers should re-set chokers (Fieber et al. 1982). Since several logs are usually pulled to the corridor

at once, this requires choker setters with training, experience and willingness to reduce this kind of damage (Burke 1975). Ultimately the control of logging and skidding damage rests with the loggers.

In addition, where practical, high skyline tension should be used to provide maximum lift during lateral skidding, and carry the load with only one end dragging in the corridor. Another serious source of injury is from not laying out corridors in a straight line. Corridors more than 400 feet long cannot be eye-balled in, since at bends logs hit edge trees. Corridors must be parallel to the slope line, and new settings established as needed, rather than relying on many corridors fanning out from a central yarding point.

In all types of skidding and yarding, tree-length and full-tree logging are far more damaging to residual trees than when trees are bucked into short lengths. Tree-length skidding causes far greater soil compaction than does full-tree logging (Mace 1970), and damage to boles increases significantly with any skidding method where trees are not bucked-up into logs (Hannah et al. 1981). Both the amount of scuffing and abrasion increases, and width and depth of scuffing wounds is greater.

SOIL COMPACTION AND EROSION

Numerous studies have dealt with the effects of tractor skidding, high-lead yarding and skylines on soil compaction, erosion and sedimentation. In general tractor logging is responsible for the greatest amount of compaction and the largest decrease in soil porosity due to the weight of the tractor and the constant use of main skid trails. This damage is particularly severe when soils are of heavy texture or wet (Fries 1977).

In Oregon studies, Dyrness (1965) found that 27 percent of the soil was compacted by tractor logging, but only 9 percent when high-lead yarding was used. Tractor logging left 36 percent of the soil area undisturbed, while 57 percent was undisturbed after cable yarding.

In 1967 studies Dyrness compared soil disturbance from high-lead systems with skylines. Areas of disturbed and compacted soils were less with skylines, but differences were small and not statistically significant. Kidd and Megahan (1972) also compared jammer and skyline yarding effects on erosion and sediment movement for highly erosive soils in Idaho using sediment dams. They found no significant differences between these two yarding methods, but there was an increase in sedimentation over unlogged areas. The more numerous roads associated with jammer systems, however, increased sedimentation 750 times over that of natural areas and this effect lasted for at least six years.

In the Appalachians, Patric and Gorman (1978) studied partially-cut areas where a Urus skyline was used. Ninety-four percent of the area showed no change in infiltration rates, bulk density, overland flow, or erosion. Only 3 percent of the logged area had severely disturbed soil. Ruth (1967) attributed the greater damage and erosion in Oregon high-lead studies to the fact that skid trails usually ran up and down the slope rather than on the contour or at an angle.

SPECIES DIFFERENCES

Since the major species of concern in this review are northern hardwoods, yellow birch, American beech, sugar and red maples and black cherry, it is important to keep in mind that these are diffuse porous woods. Shigo (1966) points out that for beech, birch and maple discoloration is often as degrading as decay, and that most discoloration in maple is due to fungi.

In some species a colored heartwood develops which is impregnated with tyloses, but maples, beech and spruce do not have this visibly different heartwood (Jorgensen 1962). Hepting et al. (1949) noted that increment borer wounds caused discoloration and decay and that these spread more rapidly in diffuse-porous woods including sugar and red maples, yellow-poplar, yellow and black birches, American beech and cucumbertree.

Wounds of yellow birch often grow larger during the first growing season, whereas those of sugar maple do not. Of 16 birch and 10 maples felled and sawn four years after logging injury, stain and decay had entered the butt logs of 7 birch and 4 were degraded. Stain and decay, however, had entered the lumber of only 1 of 7 maples (Benzic et al. 1963).

Many researchers have noted that thin-barked species, particularly in the spring when the bark is loose, are far more susceptible to debarking and scuffing wounds (Shigo 1966, Nyland and Gabriel 1971, Aho et al. 1983). Gouging wounds induce more decay than smooth wounds. Nyland and Gabriel (1971) also found northern red oak to be subject to bark scuffing.

Although no skidding or yarding studies mention black cherry as specifically susceptible to wounding, it is known that average- and low-vigor black cherry often develop cambial dieback around pruning wounds which increases the length of time a wound remains open (Zeedyk and Hough 1958).

SILVICULTURAL IMPLICATIONS

Information on cable yarding damages must be fitted into the silvicultural system to determine how critical this logging damage is to residual trees, and to the understory. It is important to keep in mind that cable yarding systems are expensive, and thus a certain volume per acre must be removed to justify the cost of setting up the equipment. Cable yarding in partially-cut areas is less attractive economically than in clearcuts since partial cuts require greater care and yield less volume per unit area.

Even-aged Management

In considering the management of quality hardwood stands, it must be remembered that many Appalachian stands are presently even-aged, since they originated after widespread clearcuttings and high gradings early in this century. Since economic considerations demand that a substantial volume be removed in any partial cut using cable yarding, it would appear that any economically-feasible partial cut using cable yarding would be a late thinning when most of the trees to be removed are at least small-timber-stage or larger.

Postponing thinnings in hardwood stands where high-quality lumber or veneer is the major management objective is a recognized silvicultural practice. In

high-quality stands, those of preferred species, seed-origin, and occupying good growing sites, keeping the stand dense until after upper-crown-class trees have reached full height growth is a recognized and accepted European practice (Moller 1954, Barrett and Holmsgaard 1964), and is being adopted in the United States where quality production is the goal (Holsoe 1947, Carvell 1983). The first low thinning, removing less vigorous codominants and less desirable species, is delayed until the stand has reached full height growth.

It is interesting to speculate that two thinnings late in the rotation would not allow discoloration and rot to advance to any great extent during the remaining years of the rotation. The second thinning should remove trees that had been damaged during the first thinning, if they had not been taken out at the time of that cutting. Rots entering the tree bole after the second thinning, which would precede the final harvest by 15 years, would not proceed to any great extent before the final cut. Thus the seriousness of bole damage from late thinnings would not be nearly as critical as similar wounds made early in the rotation.

Another factor to consider is damage to the understory. In most cable-yarding studies a large number of the damaged trees reported are small diameter trees, suppressed trees or understory saplings. Actually these trees are of little concern in timber-sized stands. Most lower-crown-class trees and understory saplings, those 1 to 5 inches dbh, are of low vigor, and if left until the final harvest serve no useful purpose as a nucleus for the next stand. Low vigor oaks will not respond when released; some die from exposure, sunscald or windthrow at the time of the final cut. If they do survive, they are often resuppressed by the flood of rapidly-growing regeneration that comes up around them. Sugar and red maples, however, regain vigor and form a significant part of the new stand.

In addition, in even-aged stand management there has been too much concern over breakage to understory woody plants. In these stands the understory is of little concern at mid-rotation. Some of these seedlings and seedling-sprouts are short-lived, others such as maples and oaks, persist and eventually serve as a nucleus of advance seedlings and seedling-sprouts for the next rotation. Actually the last thinning in northern hardwood and mixed oak stands is the important intermediate cut which stimulates the formation of a desirable seedling understory. Thus, a lot of the damage to residual trees of sapling size or smaller is not important. This does not imply that stand damage from cable logging cannot be critical, but the serious damage is to the high-quality dominant and codominant trees when the wounding occurs 20 years or more prior to the final cut.

Uneven-aged Management

In uneven-aged stands, however, the results of partial cuttings using cable yarding are potentially more serious, since all of the residual trees, regardless of size, are considered growing stock. Proper care of growing stock is the key to successful selection management. Damage to large-sapling-stage and pole-stage trees is more of a concern, since these younger trees will be left for many years, until mature. Thus, in selection cuts damage to young trees must be kept to a minimum, and trees with gouge-type wounds removed during the cutting, or at the next selection cut. Many uneven-aged stands have an abundance of trees in the 1-5 inch dbh range, and losses of the magnitude

reported from well-planned skidding and yarding operations can be tolerated.

SUMMARY

There is a definite place for cable yarding in partial cuts in even-aged Appalachian hardwood stands. Cable yarding would be desirable for late thinnings. In these thinnings unmarked trees with wounds exceeding 4 inches in width should be anticipated during marking, thus the forester would mark less volume foreseeing the need for removing additional trees during the cutting.

Proper pre-planning of the corridor locations and training of workers is essential to minimize serious damage to residual trees. Corridors must be parallel to the slope, with no bends, and of sufficient width to keep logs from hitting edge trees. The cableway must be moved when needed rather than operating from a central yarding point in a fan-shaped pattern.

Any method of removing logs from a partially-cut stand results in some injury. Less damage occurs to residuals when trees are bucked into short lengths. Numerous studies indicate that damage from cable yarding is similar to, or less than, that from tractors or skidders, but only when loggers are trained and motivated to do the least damage. Positioning the carriage so that logs do not drift downhill during skidding to the corridor is very important.

In even-aged management, damage to small trees and the understory is not as critical as in uneven-aged management. In even-aged stands suppressed trees offer little potential as a nucleus for the next rotation, and understory seedlings and saplings will have time to build-up after the last thinning, since this cut will stimulate seed production and seedling establishment.

In uneven-aged management, however, cable yarding requires greater care since all residual trees, regardless of size, are considered growing stock. Damage to sapling- and pole-stage trees is more serious, since many of these younger trees will be left for many years, until mature. Only when there is an abundance of these younger age classes, and where damage can be minimized should cable yarding be used.

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A MICROCOMPUTER PROGRAM FOR EARTHWORK CALCULATIONS

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ABSTRACT

The End Area/Earthwork Calculations program was written for the Apple II microcomputer to increase computer literacy of students and provide practitioners with an easily understood and used tool for earthwork calculations in critical areas, as an indicator of balance between cuts and fills, or an estimation of yardage for bids based on the cost per cubic yard of excavation. A special coding form was developed for ease in data entry. Inputs are derived from the usual field and office data obtained in curvilinear surveys. The program produces calculations in the standard format used by road designers. Calculations can be made in about one-tenth of the time required by hand methods.

INTRODUCTION

In forest road construction, earthwork calculations are often used to assess the balance of cut and fill during construction, and determine volumes in critical areas of heavy cuts or fills. One of the most common methods of earthwork calculations for forest roads is to use average end areas between stations. The calculation of end areas mathematically, or determination by planimeter is a tedious task, fraught with small errors, and is a natural for solution by programmable calculators or microcomputer.

As a portion of our effort to make our students computer literate, the authors designed a microcomputer program for the Apple II to perform earthwork calculations. Previously, the students were required to calculate some 30 to 40 end areas by hand, and then calculate the yardages between them to come up with an estimate of accumulated yardage. The amount of excess cut or fill serves as an indication of how well they are balanced.

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THE PROGRAM

Inputs

The program is designed to follow the same mathematical sequence used manually for the estimation of cubic yardage between each station, and the accumulated yardage as each calculation proceeds to the next station.

In the manual methods, end areas are drawn to scale based on side slope data, cut and fill information, and the road standard. At this point end areas can be mathematically determined as shown in Figure 1. When the road prism shifts from pure cut to pure fill or vice versa the runout is usually determined graphically or can be solved by mathematical proportion. When the road prisms between stations do not have a matching end area then the runout is calculated by using the respective heights above or below grade at the shoulder of the road section. These situations are shown in Figure 2.

Using similar mathematical procedures, Dr. Hokans designed a micro-computer program to calculate end areas and earthworks. The program proceeds through a series of questions to the user which leads to the inputs needed tc process the information and print it out. The required user inputs are as follows:

1. A decision of whether or not printed output is desired.

2. Enter the road standards if different than the defaults; road width 20 feet; ditch width 3 feet; cut slope ratio 1:1; fill slope ratio 1.5:1; shrink percentage of 20 percent.

3. Designating the type of road prism, i.e.; through cut (1); through fill (2) or cut and fill section (3).

4. The cut (+), or fill (-) at centerline in feet and tenths.

5. The rise of the hill, i.e. to the right or left.

6. The percent of side slope, as an absolute number, to the right of centerline.

7. The percent of sideslope, as an absolute number, to the left of centerline.

In order to expedite data entry a special coding form was designated. This form, shown in Figure 3, is completed from field or office data and is used at the computer during processing.

Outputs

After entering the above input information, the screen displays the end area of the selected road prism, the height of the road prism shoulder on the right and left of the centerline the height at centerline and the slope distance to the toe of the cut or fill slope to the right and left of centerline.

As soon as the input for the next end area is entered, and displayed, the program calls for the distance between the end areas, or stations. This entry is followed by a display of the cubic yardage of excavation (+) and embankment (-) and the accumulated yardage (+ for excavation and - for embankment).

The procedure then, is to continue inputting of the required cross section data and distance between stations, until the length of the centerline involved is a specific situation is completed.

If the printer is selected during processing, the resulting information is printed out in the standard format used by road designers. An example of this output is shown in Figure 4.

SUMMARY & CONCLUSIONS

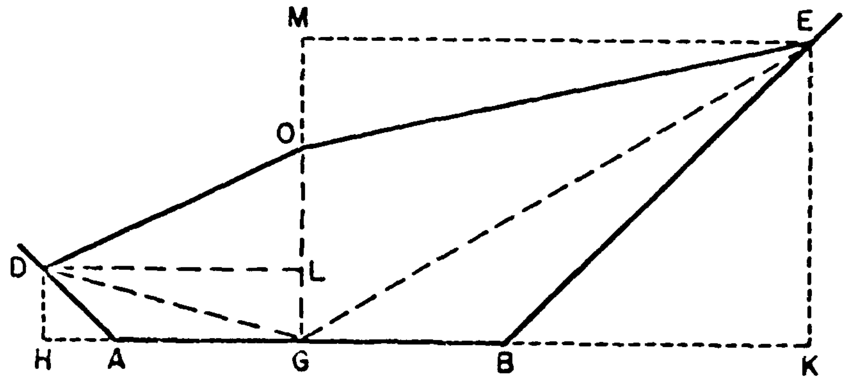
The program was tested extensively by students in the Road Location and Construction course Winter Quarter 1984 and was found to be particularly user friendly and easy to understand. What normally required 12 to 18 hours of tedious calculations now requires about 1 hour.

At this writing the only limitation to the program is that it will not calculate end areas if there are opposing ground slopes. In these cases the end area is drawn to scale and an estimate made of a ground slope percentage which would result in approximately the same end area. This percent of slope is then used in the program.

Future modifications will be made to provide the ability to dump accumulated excavation as would be done in the field during construction. In addition, there will be a provision to allow input of "special cases" as a part of the calculations.

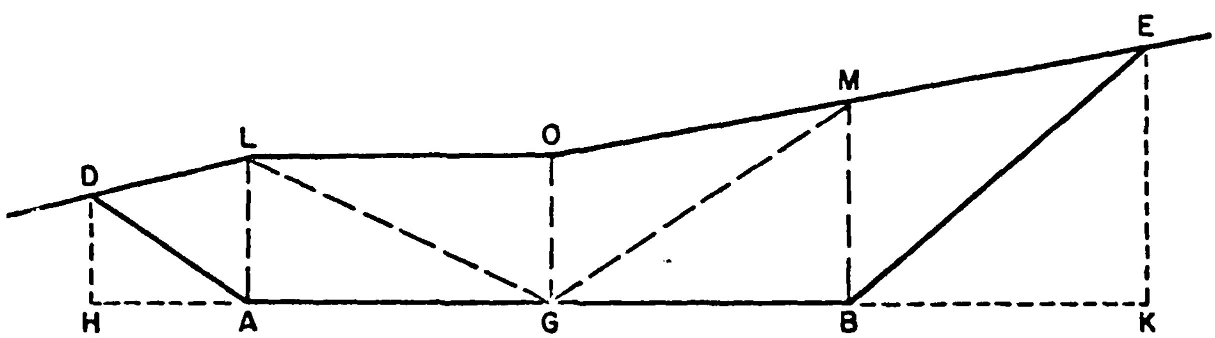
The program has proven to be a good practical demonstration of microcomputer application, and has satisfied the objective of further computer literacy for our students. For practitioners it can be an excellent tool for earthwork calculations in critical areas, as an indicator of balance between cuts and fills, or an estimation of yardage for bids based on the cost per cubic yard of excavation.

For information regarding additional details about the program and its availability, contact either author at The Department of Forestry, Virginia Tech, Blacksburg, VA 24061.



$$\text{AREA} = OGD + OGE + GBE + AGD$$
$$= \left[(1/2\ OG \times DL) + (1/2\ OG \times ME)\right] + \left[(1/2\ GB \times EK) + (1/2\ AG \times DH)\right]$$
$$= \frac{c(d_l + d_r) + b/2\,(h_l + h_r)}{2}$$

WHERE: c = CUT OR FILL AT CENTER LINE, OG
d_l = DISTANCE OUT FROM CENTER LINE, DL
d_r = DISTANCE OUT FROM CENTER LINE, ME
h_l = HEIGHT ABOVE GRADE, DH
h_r = HEIGHT ABOVE GRADE, EK



$$\text{AREA} = LOMG + DLGA + GMEB$$
$$= \frac{cb + f_l d_l + f_r d_r}{2}$$

WHERE: c = CUT OR FILL AT CENTER LINE, OG
b = BASE, AB
f_l = HEIGHT ABOVE GRADE, LA
f_r = HEIGHT ABOVE GRADE, MB
d_l = DISTANCE FROM CENTER LINE, GH
d_r = DISTANCE FROM CENTER LINE, GK

Figure 1: Typical Formulae for the Calculations of End Areas

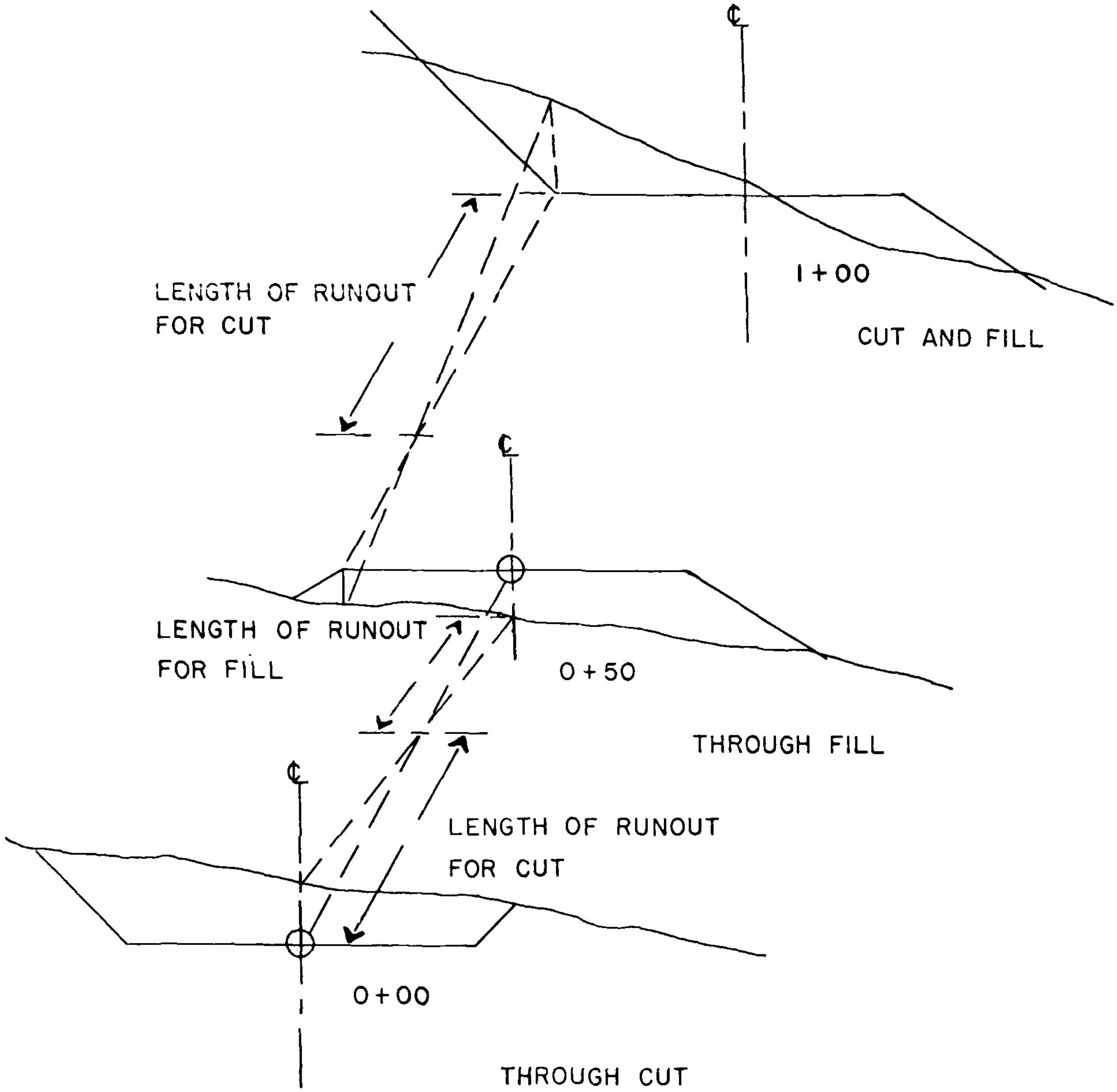


Figure 2: Heights at centerline or shoulder of road prism for the determination of runout distances.

FOR 3710 - Road Location & Construction

Format for Earthwork Program Input

Program Station	L-Line Station	Dist	Form of X-Section (1)(2)(3)	Cut(+) Fill(-) @ ℄	Rise of Hill (R)(L)	% Slope R	% Slope L
1	0+00		3	-0.5	L	20	30
		50					
2	0+50		2	-2.0	L	15	35
		30					
3	0+80		1	+3.7	L	10	20
4	etc.						

* Form of X section : Thru cut = 1; thru fill = 2; and cut & fill = 3

Figure 3: The coding form used for inputting field and office data to obtain earthwork calculations.

END AREA - EARTH WORK CALCULATIONS

DISTANCES IN FEET - - - - - VOLUMES IN CUBIC YARDS

		END AREAS		VOLUME		ACCUM.	LEFT HT.	RIGHT HT.
STA	DIST	CUT	FILL	CUT	FILL	VOLUME	SLOPE D	SLOPE D
1		27.5	22.1				2.5	-2.5
	50			10.6	72.3	-61.6	18.6	15.6
2		0	42.9				1.5	3.5
	30			47.6	10.0	-24.1	9.0	16.9
3		132.0	0				5.7	2.7
							21.2	15.2

ROAD STANDARD

ROAD WIDTH....... 20 FEET
DITCH WIDTH...... 3 FEET
CUT SLOPE RUN 1, RISE 1
FILL SLOPE RUN 1.5, RISE 1
% SHRINKAGE = 20

Figure 4: An example of the printout generated by the program.

COMPUTER AIDED TIMBER HARVEST PLANNING: AN EXAMPLE

by

Roger H. Twito
Robert J. McGaughey

ABSTRACT

A desk-top computer program called PLANS (Preliminary Logging ANalysis System) provides increased efficiency in developing timber harvest plans. The time savings realized by the use of PLANS should permit more thorough examination of logging system designs and cost analyses. PLANS was used to develop a logging system and transportation plan on a 3200-acre commercial forest tract in the Cascade Range in Washington. The paper outlines an approach for developing this plan, compares the operating characteristics of PLANS with a conventional computer-based skyline design method, and presents results of the timber harvest plan.

COMPUTER AIDED TIMBER HARVEST PLANNING: AN EXAMPLE

Roger H. Twito[1]
Robert J. McGaughey[1]

REVIEW OF TIMBER HARVEST PLANNING

Most logging engineers would agree that preliminary layout of timber harvest units and roads on topographic maps is a vital prerequisite to harvesting operations. This is especially true in rugged mountainous terrain requiring cable systems because efficient log yarding in those areas depends on how much log weight the tightened skyline can lift and transport along its span. The procedures used to develop timber harvest plans are loosely structured, however, and vary with the planner. No university level text has been written to explain how such plans should be developed. Because standards do not exist for timber harvest planning, the end product varies greatly in quality and detail. To a great extent the quality of timber harvest plans is influenced by the planner's professional inclination, which in turn is affected by time constraints, management support, and the planning tools provided. An emphasis of the Forest Engineering Research Unit (Pacific Northwest Forest and Range Experiment Station) in Seattle has been to provide better planning tools and methods.

A review of the evolution of skyline harvest planning shows that as each of the new methods became available, the quality of planning improved. The "chain and board" analysis (Lysons and Mann 1967) provided a method to make skyline payload determination feasible using topographic maps or field run profiles. Later, desk-top computer systems paved the way for great improvements in this process and, via documented programs (Carson 1975), provided means to conveniently display terrain profiles and calculate allowable payloads. Further improvement in desk-top computers led to cosmetic and operational improvements in this basic technique. The program developed by the Pacific Northwest Region in Portland, named "LOGGER" (USDA Forest Service 1980), is the current standard for skyline analysis. It has been interesting to see how, as these methods were accepted, a following developed that refused to upgrade when better techniques became available. There are practitioners, for example, who still are not interested in using any method except chain and board analysis.

Human factors weigh heavily when forsaking the old and adopting the new. We would concede that for many aspects of skyline analysis, programs such as LOGGER are very adequate. It is an excellent method for the detailed analysis of individual profiles, and this is what is required for intensive project level work and skyline layout. Current microcomputers have, however, opened the door for harvest planning to be extended beyond project level planning to

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a different and broader level. This broader level can be characterized as more streamlined and efficient for extending planning over larger areas. This is the level of harvest planning our research unit had in mind when we began work on a set of programs called PLANS (for Preliminary Logging ANalysis System) (Twito and Mifflin 1983). We believe that PLANS can provide a foundation to make the preliminary planning of timber harvest units and timber access roads more convenient, and lead to a more structured and thorough planning process.

DESIGN FEATURES OF PLANS

Certain features were incorporated in the PLANS package for the purpose of making it effective for rapid planning from topographic map data. The programs are designed to calculate or print only the detail needed for the intended level of planning.

PLANS is based on the use of a digital terrain model stored in a permanent data file. This eliminates the need for repeated digitizing of elevation data needed for skyline or road analysis. During the design process the digitizer is simply used as a device to point out selected control points from the base map, or to locate and mark computer-generated control points on the base map.

Individual programs contained in the PLANS package are:

1. SKYSET: This program directly solves for maximum skyline span with a stipulated payload, or the maximum skyline payload with a stipulated span on fan-shaped skyline settings. Prior skyline analysis programs may require repetitive runs and payload examination to determine these variables.

2. SKY1: Similar to SKYSET except it is designed for mobile yarders operating from parallel settings.

3. HIGH_L: This program designs highlead yarding units.

4. ROAD: Locates roads on a uniform grade between control points and calculates the minimum excavation and clearing quantities for the route based upon side cast construction.

5. SLOPE: Plots base map overlays showing slope information from the digital terrain model.

6. VISUAL: Plots perspective drawings of the terrain, roads, and harvest units as seen from specified viewing points.

7. YARDING COST: Calculates yarding production and cost using a simulated timber stand, regression equations, and the allowable yarding payload.

Additional programs to be added to PLANS are under development but are not ready for use.

A test version of PLANS was made available to National Forests and industry in 1982. Our purpose, beyond making this technology available for use, was to receive helpful suggestions for desired program modifications prior to publication. The feedback resulted in revisions released in 1983.

Although we received support and encouragement for PLANS from National Forest personnel, we did not get feedback that vicariously satisfied our need to experience the success and frustration of using PLANS for timber harvest planning. Therefore, when our project was given responsibility for developing a logging system and transportation plan for the Panther Creek division of the Wind River Experimental Forest, Gifford Pinchot National Forest, in southwest Washington, we elected to use PLANS for this project. We did so not only to personally give PLANS a full test on this large 3,200 acre project, but because we thought it would be the best method available for developing the timber harvest plan.

SUMMARY OF THE TIMBER HARVEST PLAN

The major yarding systems considered in the development of the Panther Creek plan are detailed in Table 1.

Table 1. Data on the yarding systems used on Panther Creek Unit timber harvest plan

Yarder	System	Working line diameter (inches)	Maximum reach (feet)	Carriage weight (pounds)	Hourly operating cost
Washington 118	Running skyline	7/8 haulback	1,600	600	$176.78
Skagit BU-199	Live skyline (slackline)	1-3/8 skyline	2,700	4,200	$333.34
Skagit 739	Highlead	1-3/8 mainline	1,200	None	$230.74

These systems, or valid substitutes, are available in the proximity of the planning area, and provide a reasonable combination of yarding capacities for the terrain involved. In general the highlead system was applied to the more gently sloped and accessible benches. Skylines were used where yarding over streams required full suspension of the logs, and on the steeper terrain. The running skyline was used where good deflection patterns could be sustained by parallel settings along the existing roads. The slackline system with its longer reach was used from ridgetop landings where longer spans across streams

were needed to gain adequate deflection. Mapped depictions of our plan are shown in Figures 1 and 2. The original base map and planning were done using a 1:4800 scale (1 inch = 400 feet), but the reduction necessary for printing permits only a general understanding of the detail required.

The volume assumptions for the harvested stands on which the yarding cost analysis was based are shown in Table 2. This volume is not necessarily present throughout the area now. We have assumed it will be at the time of the final harvest cut.

Table 2. Timber stand data assumed for yarding cost analysis on Panther Creek Unit

Stand	Average d.b.h. (inches)	Average volume/tree (board feet)	Merchantable trees/acre	Volume per acre (M bf) (Scribner)
1	24.5	605	86	52
2	20.0	349	86	30

Only 12 percent of the area analyzed was in the lower volume class stand (30 M bf/acre). All of this area fell into highlead units.

The yarding cost analysis was developed using the YARDING COST program. The accuracy of the cost projections obtained from this program is suspect primarily because we could not locate production regression equations (Aubuchon 1982) that completely fit our yarding situation. A number of the elements accepted as influential to production have been calculated accurately: these include yarding distances, allowable system payload, and a reasonable simulated dispersion of logs. The ability to efficiently model these parameters will make it even more imperative to obtain reliable regression information. The yarding cost summary is given in Table 3.

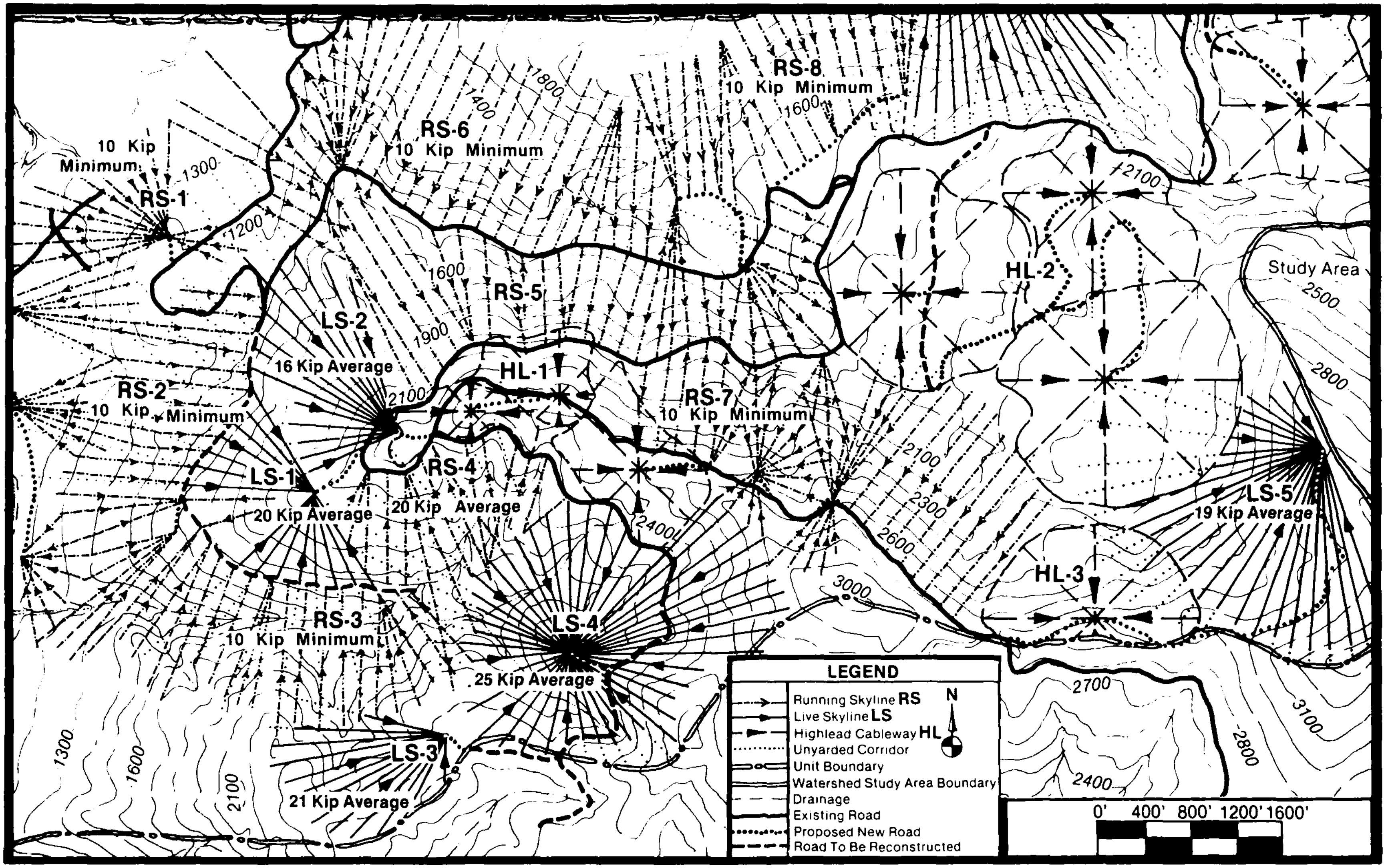

Figure 1. Logging and transportation plan of the west portion of the Panther Creek Unit.

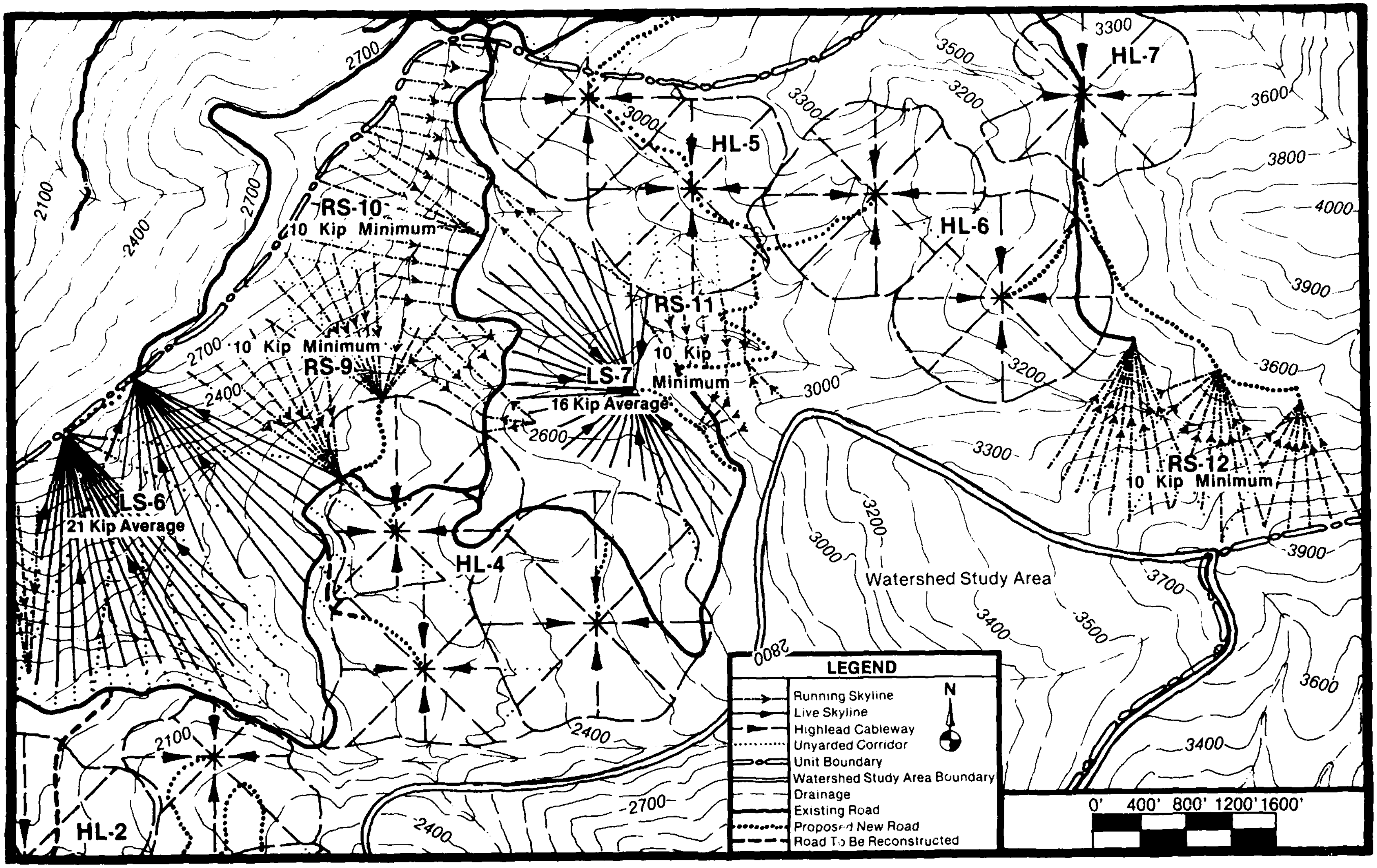

Figure 2. Logging and transportation plan of the east portion of the Panther Creek Unit.

Table 3. Yarding cost summary on the Panther Creek Unit

Yarding system	Total volume (M bf)	Total cost ($)	Average yarding distance (feet)	Area (acres)	Time required (hours)	Production per day (M bf)	Yarding cost ($/M bf)
Running	45,380	1,201,277	708	872	6,795	53.5	26.47
Slackline	28,558	1,008,939	1,154	549	3,027	75.6	35.33
Highlead	28,877	900,375	505	664	3,902	59.2	31.18
Tractor or Jammer	6,023	166,122	--	116	3,633	13.3	28.75
Total	108,838	3,276,713		2,201	17,357		

We attempted, and were reasonably successful at, using the existing road network for timber access. Some reconstruction and new construction was needed to provide full yarding coverage to the drainage area. The road summary is shown in Table 4.

Table 4. Road cost summary for the Panther Creek Unit

Road category	Length (miles)	Unit cost ($/mile)	Total cost ($)
Existing roads			
Currently usable	8.79		
Reconstruction needed	1.72	49,000	84,280
Proposed new roads			
12-foot surface-highlead access	3.37	55,000	185,320
16-foot surface-slackline access	4.20	72,000	302,400
Total	18.08		572,000

RECOMMENDATIONS AND CONCLUSIONS

The first step in developing a timber harvest plan is to formulate an overall strategy. The computer is no help here, because there is no way for it to match the human brain in sensing the patterns of opportunity that the topography provides for ample skyline spans and coverage. We found it helpful to color code a print of the contour map with a promising network of skyline spans and landings that could provide full yarding coverage for the planning area. The choice of yarding systems with their available maximum reach must be made prior to this.

The next step is to use the appropriate skyline programs to roughly check the assumed landing locations. Here the speed of analysis with the digital terrain model used in the PLANS programs provides a great advantage in quickly checking a sampling of the skyline settings. When comparing the time requirements for our analysis with those for LOGGER, which requires digitized profiles, we found the PLANS routines four to five times as fast. The quick check of the landings often disclosed that adjusting their location would improve the skyline performance and payload. After the most promising landing locations were checked, a more thorough analysis began. We designed nearly every setting required to log the area. This complete an analysis may not always be necessary, but it did not take any more time to analyze a setting than it did to wonder about whether it should or should not be analyzed.

Using the PLANS skyline programs made it easier to give up on a marginal landing location and to check for better possible locations. This was largely true because redigitizing of new profiles was not required. The digitizing and storing of the PLANS digital terrain models for the Panther Creek Unit did, however, take an experienced technician about 20 hours. This work can easily be done by people lacking planning skills. The planning cost summary is shown in Table 5.

Table 5. Planning cost summary for the Panther Creek Unit

Function	Time required (hours)	Cost[1] ($)	Cost per acre ($)
Building the digital terrain model	20	250	0.08
Developing the timber harvest plan	90	1,125	0.35
Total	110	1,375	0.43

[1] Cost is approximated at $12.50 per hour.

Since the indicated cost for implementing this timber harvest plan is about $3,850,000, preliminary planning costs of 0.0004 percent of that total are inconsequential.

When full yarding coverage is developed, certain stands can be accessed from two or more landings. A final step in this portion of design was to therefore redesign the yarding patterns to prevent overlap. Generally we planned to yard the stand to the closest landing unless payload or yarding system cost dictated otherwise.

The time savings made possible by use of an efficient planning program such as PLANS creates opportunity for designing alternative harvest layouts. This repetition of effort can be worthwhile because of the potential savings attainable by comparing the estimated cost of each layout. We were, unfortunately, not able to provide a meaningful example of that practice for this paper, mainly because the terrain and existing road network in the Panther Creek Unit provide very few harvest planning options. Our initial strategy was to use the existing road system to the greatest extent possible. Most of the remaining stands were reached from short spur roads to proposed landings from which slackline or highlead systems provided needed coverage. We believe there were no other imperative options to consider after the initial design was completed. Other reasons for omitting alternative analyses involve the timing and length of subject matter that can be adequately covered in a symposium presentation. The preparation of only one harvest plan at this time in no way negates the desirability of digital terrain models for planning. This present plan is merely a good first proposal which will be subsequently reviewed by members of a multi-disciplinary planning team. Not only did the digital terrain model base save the planning time during the initial development of the plan, but it will ease the burden of making needed modifications.

The final conclusion we draw from our use of PLANS on this project is this: These programs were designed to focus on a specific, important, but perplexing level of planning. Some National Forest colleagues have asked if we had ever applied PLANS to a "real world" planning project. Now we have. We conclude that it works very well.

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THE EFFECT OF TRUCK DESIGN ON ROAD STANDARDS, ROAD CONSTRUCTION AND TIMBER HAULING COSTS IN SOUTHWEST VIRGINIA

Hank Sloan

ABSTRACT

A case study roading project was examined for construction cost and timber haul cost for various design trucks. Selection of design truck had less than four percent variation in construction costs. Haul costs showed approximately ninety percent variation among design trucks; therefore, the most economically efficient roading project is one which provides for the most efficient timber hauling design truck.

INTRODUCTION

Road construction costs are controlled to a large extent by the design standards specified. These specified standards are a direct result of the road design process. The design process objectives are to meet design criteria through proper selection and application of design elements and standards for a given purpose.

Design criteria are those requirements that govern selection of elements and standards for a road or section of road.

Design elements are the physical characteristics of a road such as traveled width, shoulders, slopes, curve widening, and pavement structures which, when combined comprise the planned facility.

Design standards are the definitive lengths, widths, and depths of the individual elements.

The Forest Service has identified nine design criteria that serve as the decision basis for the design elements and standards (U.S.F.S., 1982). They are: resource management objectives, environmental constraints, safety, physical environmental factors, traffic requirements, traffic service levels, vehicle characteristics, road user, and economics. It is this last design criteria, economics, that this paper is focusing on.

Forest development roads shall be designed to serve the projected traffic requirements at the lowest cost for transportation (lowest total for construction plus maintenance and user costs) consistent with environmental protection and safety considerations (U.S.F.S., 1982). It is the purpose of this paper to examine on a case study basis the relationships between design log trucks and their effect on road construction and timber hauling costs. The methodology used to examine these relationships is to first, accurately define the various design truck configurations and develop the data necessary to predict their hauling costs, and second, to develop the cost of a case study road project for the various truck configurations by calculating the various quantities and costs of the design elements, and last, to make comparisons in order to reach conclusions about economics as a design criteria.

LOG TRUCK DESIGNS AND HAUL COST COMPUTATIONS FOR WESTERN VIRGINIA

Introduction

The computer aided road design system (RDS) has incorporated an equation which generates curve widening based upon a given wheelbase. The wheelbase chosen is from a vehicle which through design can travel the road with acceptable clearance. This vehicle is referred to as the design vehicle. Since haul costs usually are the single largest development cost in harvesting, this design vehicle plays a large role in the ultimate management costs of timber in a given trafficshed.

To compare the haul costs of various truck configurations some assumptions must be made in order to place the alternative trucks on equal ground. These are:

1) Log truck configurations and pay loads will conform to the size and weight requirements of the State of Virginia. It may be common practice for loggers to load their trucks to their physical capacity rather than their legal capacity in order to reduce per unit costs.

2) List price of new log trucks will be used in developing truck machine rates. This is necessary to eliminate the variability with making a "deal" on purchasing a particular truck.

3) Haul is limiting logging production. Skidding costs are equal. This implies that the landings for the various trucks serve the same acreage. Although there is a tendency among loggers with bigger trucks to have fewer landings/sale this assumption is necessary in order to eliminate the consideration of differing skidding costs.

4) The various truck configurations will travel the specified haul route at the same average rate. The trucks will be speced out for quote to provide equal performance for relative payload. Drivers's ability increases with truck size. This is necessary to eliminate the over building or under building of a given truck configuration and to simplify computations.

Weight Limitations

The State of Virginia bases its licensing and weighing of trucks for conformance to regulations on what is commonly referred to as a "bridge law" formula. This law is reflected in the following table:

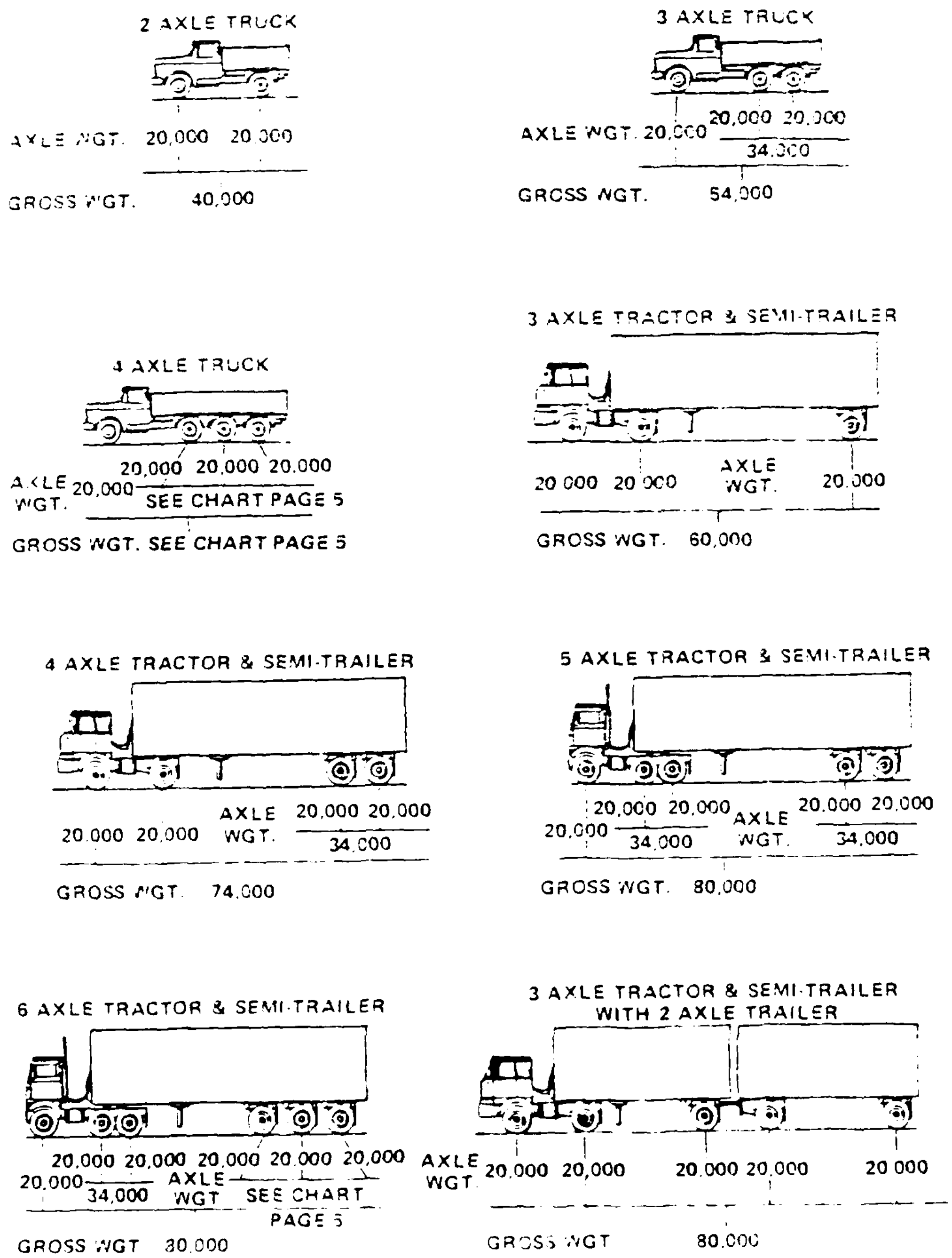
WEIGHT ALLOWED BASED ON AXLE SPACING (Virginia 1983)

The total gross weight imposed upon the highway by a vehicle or combination shall not exceed the maximum weight given for the respective distance between the first and last axle of the group of axles measured longitudinally to the nearest foot as set forth in the following table:

DISTANCE IN FEET BETWEEN THE EXTREMES OF ANY TWO OR MORE CONSECUTIVE AXLES	MAXIMUM WEIGHT IN POUNDS BETWEEN THE EXTREMES OF ANY TWO OR MORE CONSECUTIVE AXLES				
	2 AXLES	3 AXLES	4 AXLES	5 AXLES	6 AXLES
4	34 000				
5	34,000				
6	34 000				
7	34 000				
8	34 000	34 000			
9	39 000	42,500			
10	40 000	43,500			
11		44 000			
12		45,000	50,000		
13		45 500	50,500		
14		46 500	51,500		
15		47 000	52,000		
16		48 000	52,500	58 000	
17		48 500	53,500	58 500	
18		49 500	54 000	59 000	
19		50,000	54 500	60 000	
20		51,000	55,500	60,500	66 000
21		51,500	56,000	61,000	66 500
22		52,500	56,500	61,500	67 000
23		53 000	57,500	62,500	68 000
24		54 000	58,000	63,000	68 500
25		54,500	58,500	63,500	69 000
26		55,500	59,500	64,000	69,500
27		56 000	60,000	65,000	70 000
28		57,000	60,500	65,500	71,000
29		57 500	61 500	66,000	71 500
30		58 500	62 000	66,500	72,000
31		59 000	62 500	67,500	72,500
32		60 000	63 500	68 000	73 000
33			64 000	68 500	74 000
34			64 500	69 000	74 500
35			65 500	70 000	75 000
36			66 000	70 500	75 500
37			66 500	71 000	76,000
38			67 500	72 000	77 000
39			68 000	72 500	77 500
40			68 500	73 000	78 000
41			69 500	73 500	78 500
42			70 000	74 000	79 000
43			70 500	75 000	80 000
44			71 500	75 500	
45			72 000	76 000	
46			72 500	76 500	
47			73 500	77 500	
48			74 000	78 000	
49			74 500	78 500	
50			75 500	79 000	
51			76 000	80 000	

As one can see from the table, increasing the wheelbase also increases the gross weight allowed up to the following maximums.

WEIGHT LIMITATIONS

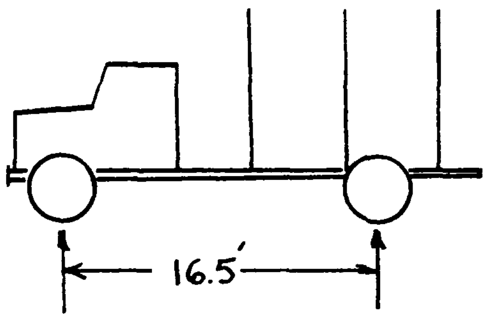


In practice it is possible to carry the same weight on the front axle as the rear axle only in those cases where the truck is designed to permit a 50-50 weight distribution between axles on a two axle truck. Therefore, the purchaser of a new truck should select a wheelbase and axle spacing which allows the truck to be loaded to a practical axle loading and gross weight not to exceed the state's maximum allowed. This is the rationale for arriving at the various log truck designs, axle loadings, and legal payloads.

Log Truck Descriptions and Payloads

In consideration of the aforementioned the following log trucks and payloads are considered in this paper.

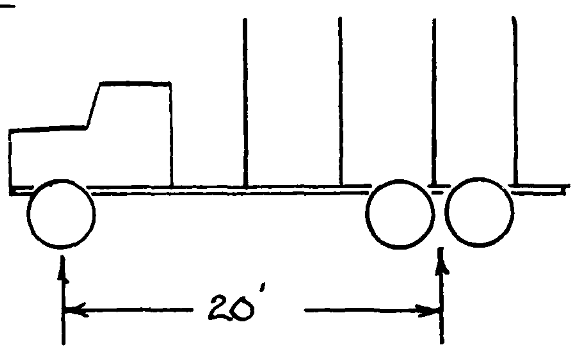
BOBTAIL TRUCK



			Total
Gross	10000#	20000#	30000#
Tare	7130#	4435#	11565#
Wood	2870#	15565#	18435#

Payload = 18400#

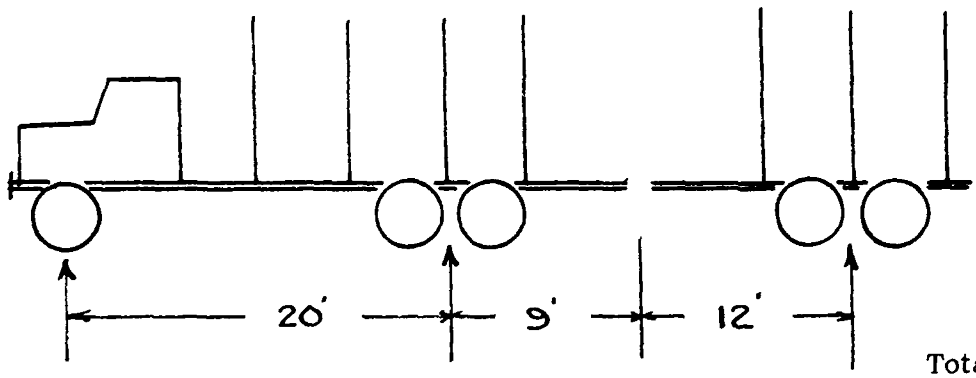
TANDEM TRUCK



			Total
Gross	14000#	34000#	48000#
Tare	7505#	11425#	18930#
Wood	6495#	22575#	29070#

Payload = 29100#

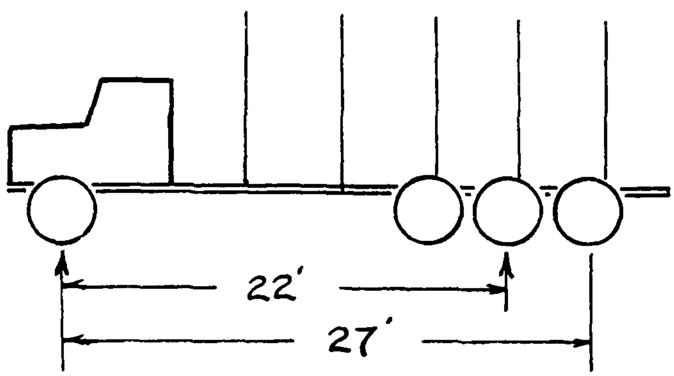
TANDEM TRUCK W/PONY TRAILER



				Total
Gross	14000#	34000#	27000#	75000#
Tare	7505#	11425#	7000#	25930#
Wood	6495#	22575#	20000#	49070#

Payload = 49100#

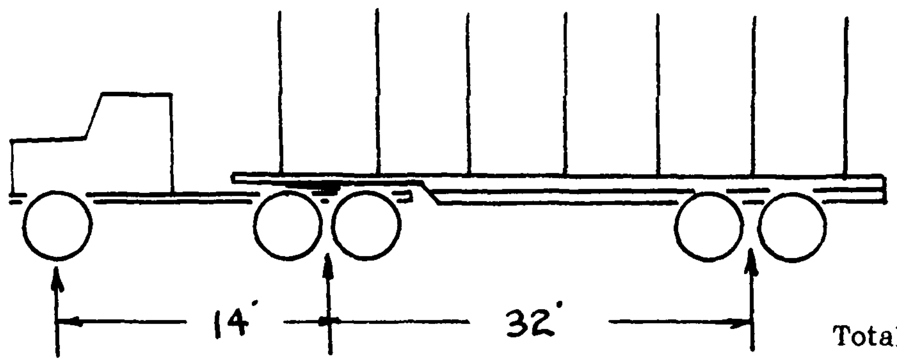
TRIAXLE TRUCK



			Total
Gross	17500#	42500#	60000#
Tare	7880#	14990#	22870#
Wood	9620#	27510#	37130#

Payload = 37100#

TRACTOR SEMI TRAILER



				Total
Gross	10000#	34000#	34000#	78000#
Tare	7345#	10460#	9000#	26805#
Wood	2655#	23540#	25000#	51195#

Payload = 51200#

Round Trip Elements and Assumptions

Truck speed will vary according to the road type. Koger (1981) observed the following average haul speeds.

Logging Road	6.85 MPH
Gravel	15.06 MPH
Two Lane Road	36.27 MPH
Interstate	50.41 MPH

This data was collected from 17 logging operations in North Carolina, Georgia, Alabama, Tennessee, and Kentucky. This information can serve as a guide in determining average haul speeds for a specific job.

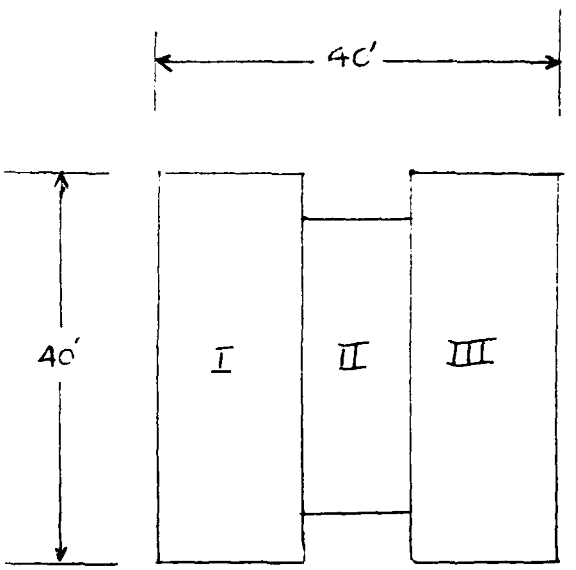
Jile and Lehman (1960) found that delay time in the haul cycle was related to road type and was 5 min./mile woods road, 1.3 min./mile graded roads and .1 min./mile on paved roads. These delays are driver related (stops for snacks, personal, etc.) and need to be considered in estimating cycle times.

Unloading time is highly variable and estimates need to take into consideration: product hauled, woodyard arrangement, type of unloader, time of day, etc. Observations and experience with a specific woodyard are the best ways to estimate average unloading time.

Loading time is a function of the size and specification of the loader, piece size, landing arrangement, payload of truck, etc. Clair (1977) found that trees loaded per productive hour was a function of product being loaded and capacity of the loader. His regression predicts that a 14000# loader loading merchandized material will load 67 trees per productive hour.

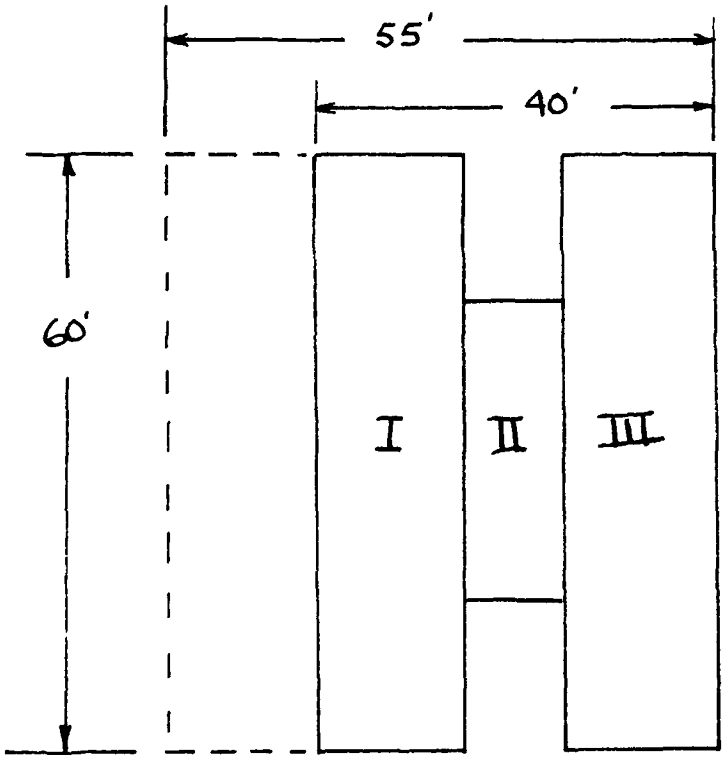
Landing size and truck size are directly proportional. The following plan view represents the differences considered between straight trucks and tractor semi trailer trucks. A suitable turnaround spot is assumed to occur within an acceptable distance from each landing.

I. Straight Truck



I Loading Hole
II Loader Set
III Deck

II. Tractor Semi Trailer



- - Area needed w/set out

	Straight Truck	Truck & Trailer	Truck & Trailer w/set-out
Excavation @ \$2.00/yd 10-20% S.S.	30 - 60 yd^3 \$90.00	45 - 90 yd^3 \$135.00	85 - 170 yd^3 \$225.00
Clear & Grubb at \$800/AC	1600 FT^2 30.00	2400 FT^2 45.00	3300 FT^2 60.00
Seed & closeout at \$800/AC	1600 FT^2 30.00	2400 FT^2 45.00	3300 FT^2 60.00

Landing Cost -	Straight truck	\$150.00
	Tractor Semi Trailer	225.00
	Tractor Semi Set Trailer	375.00
	Straight Truck w/pony	225.00

Fuel consumption of log trucks is an interaction of a given truck's specifications and its operating environment. An informal survey among operators shows a range of from 4 to 8 miles per gallon average. Cummins Engine Company, Inc. has developed a computer program to predict fuel consumption. The following vehicle evaluations of a triaxle and a tractor semi trailer show 6.17 and 6.25 miles per gallon, at a cruise speed of 55 miles per hour.

CUMMINS ENGINE COMPANY, INC.

VEHICLE EVALUATION

RUSS SPANGLER
U. S. FOREST SERVICE - HANK SLOAN

VEHICLE - 8 X 4	GVW/GCW = 60000 LB	TIRES --- (498 REV/MILE)
MAKE - IHC	WIDTH = 8.00 FT	STEER - 11X22.5 R/S-TR
MODEL - S-SERIES	HEIGHT = 13.60 FT	DRIVE - 11X22.5 R/S-TR
BODY - STAKE	AERO AID = NONE	DEAD - 11X22.5 R/S-TR

ENGINE - - CUMMINS NTC-300
C-4122-A 1 CPL 529

300 HP AT 2100 RPM
1000 LB-FT AT 1300 RPM (248 HP)
TORQUE RISE = 33 PERCENT

ACCESSORY POWER AT 2100 RPM
COOLING FAN = .0 HP
POWER STEERING = .0 HP
AIR CONDITIONER = .0 HP
POWER-TAKE-OFF = .0 HP
ALT/GEN DRAWS 10 AMP AT 14 V

DRIVETRAIN - TRANSMISSION = FULLER RT-14609A
DRIVE AXLE = I-H RA-472 RATIO = 4.330

PERFORMANCE IN GEARS --

GEAR	TRANS RATIO	OVERALL RATIO	START ABILITY (PCT)	AT 1300 RPM SPEED (MPH)	AT 1300 RPM GRADE (PCT)	TRANS-SHIFT-POINT ENGIN (RPM)	TRANS-SHIFT-POINT SPEED (MPH)	TRANS-SHIFT-POINT GRADE (PCT)	AT 2100 RPM SPEED (MPH)	AT 2100 RPM GRADE (PCT)
L	12.65	54.77	27.2	2.9	55.7				4.6	38.6
1	8.38	36.28	18.0	4.3	33.8	1391	4.6	33.3	7.0	24.3
2	6.22	26.93	13.4	5.8	24.3	1559	7.0	22.6	9.4	17.6
3	4.57	19.80	9.8	7.9	17.4	1544	9.4	16.4	12.8	12.6
4	3.40	14.72		10.6	13.0	1562	12.8	12.1	17.2	9.3
5	2.46	10.67		14.7	9.1	1522	17.2	8.6	23.7	6.4
6	1.83	7.92		19.8	6.5	1560	23.7	6.0	31.9	4.4
7	1.34	5.80		27.0	4.4	1538	31.9	4.0	43.6	2.6
8	1.00	4.33		36.2	2.9	1567	43.6	2.4	58.4	1.1

DRIVE-ABILITY IN CRUISE GEAR --

		MINIMUM SPEED	CRUISE SPEED	GEARED SPEED	GOVERN SPEED
IN GEAR 8	ROAD SPEED (MPH) =	36.2	55.0	58.4	62.5
	ENGINE SPEED (RPM) =	1300	1976	2100	2244
	CRUISE ECONOMY (MPG) =		6.17	5.65	5.06
	GRADE-ABILITY (PCT) =	2.9	1.4	1.1	.0

CUMMINS ENGINE COMPANY, INC.

VEHICLE EVALUATION

ROBERT DUNBAR
U. S. FOREST SERVICE

VEHICLE - 6 X 4-2S	GVW/GCW = 76000 LB	TIRES --- (498 REV/MILE)	
MAKE - IHC	WIDTH = 8.00 FT	STEER - 11X22.5 R/S-TR	
MODEL - S-SERIES	HEIGHT =13.60 FT	DRIVE - 11X22.5 R/S-TR	
BODY - LOG TRAILER	AERO AID = NONE	DEAD - 11X22.5 R/S-TR	

ENGINE -- CUMMINS NTC-300BCIII
CO-4122-A 1 CPL 529

300 HP AT 2100 RPM
1000 LB-FT AT 1300 RPM (248 HP)
TORQUE RISE = 33 PERCENT

ACCESSORY POWER AT 2100 RPM
COOLING FAN = .0 HP
POWER STEERING = .0 HP
AIR CONDITIONER = .0 HP
POWER TAKE-OFF = .0 HP
ALT/GEN DRAWS 10 AMP AT 14 V

DRIVETRAIN - TRANSMISSION = FULLER RT-11609A
DRIVE AXLE = I-H RA-472 RATIO = 4.110

PERFORMANCE IN GEARS --

GEAR	TRANS RATIO	OVERALL RATIO	START ABILITY (PCT)	AT 1300 RPM SPEED (MPH)	AT 1300 RPM GRADE (PCT)	TRANS-SHIFT-POINT ENGIN (RPM)	TRANS-SHIFT-POINT SPEED (MPH)	TRANS-SHIFT-POINT GRADE (PCT)	AT 2100 RPM SPEED (MPH)	AT 2100 RPM GRADE (PCT)
L	12.65	51.99	20.4	3.0	39.1				4.9	28.0
1	8.38	34.44	13.5	4.5	24.6	1391	4.9	24.3	7.3	17.9
2	6.22	25.56	10.0	6.1	17.9	1559	7.3	16.7	9.9	13.0
3	4.57	18.79		8.3	12.9	1544	9.9	12.1	13.5	9.3
4	3.40	13.97		11.2	9.6	1562	13.5	8.9	18.1	6.9
5	2.46	10.13		15.5	6.7	1522	18.1	6.3	25.0	4.7
6	1.83	7.52		20.8	4.7	1560	25.0	4.3	33.6	3.1
7	1.34	5.51		28.4	3.1	1538	33.6	2.8	45.9	1.8
8	1.00	4.11		38.1	2.0	1567	45.9	1.6	61.6	.6

DRIVE-ABILITY IN CRUISE GEAR --

		MINIMUM SPEED	CRUISE SPEED	GEARED SPEED	GOVERN SPEED
IN GEAR 8	ROAD SPEED (MPH) =	38.1	55.0	61.6	65.3
	ENGINE SPEED (RPM) =	1300	1876	2100	2226
	CRUISE ECONOMY (MPG) =		6.25	5.37	4.89
	GRADE-ABILITY (PCT) =	2.0	1.1	.6	.0
IN GEAR 7	ROAD SPEED (MPH) =	28.4	55.0	45.9	50.3
	ENGINE SPEED (RPM) =	1300	****	2100	2299
	CRUISE ECONOMY (MPG) =		****	6.17	5.45
	GRADE-ABILITY (PCT) =	3.1	****	1.8	.0

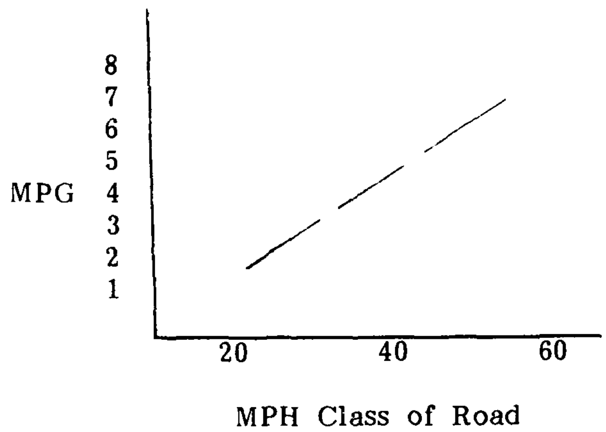
In order to establish comparative fuel consumption information the following assumptions were made:

From a dynomometer test of a popular diesel engine the average reading of .35 lb/BHP hrs. was taken across its operating range of engine speed.

By assuming that while traveling loaded the engine averages 2/3 loading of the brake horsepower available and that traveling unloaded the engine averages 1/3 loading of the brake horsepower available. Fuel consumption can be reduced to:

$$\text{GAL/HR} = (.35\ \text{\#/BHP HR})\ \frac{(1/3\ +\ 2/3)}{2}\ \left(\frac{\text{GAL}}{6.87\#}\right)\ (\text{BHP Engine})$$

$$= \qquad \text{GAL/HR} = (\text{BHP Truck})\ (.0255)$$



For typical 300 BHP Diesel

In summary the data which will be used for this comparison is:

Average Haul Speed: Forest Road = 7 MPH
Gravel State Secondary = 15 MPH
Paved State Secondary = 20 MPH
Paved State Primary = 35 MPH

These average speeds include operating driver delays:

Unloading Time: 20 minutes average

Landing Cost:	Straight truck	\$150.00
	Tractor semi trailer	\$225.00
	Tractor w/set out trailer	\$375.00
	Straight truck w/pony trailer	\$225.00

Fuel Consumption: GAL/HR = (BHP Truck) (.0255)

Loading Time: 1000#/min. plus delay/cycle as follows:

Straight Truck	5 min.
Truck w/Trailer	15 min.
Truck w/Set out trailer	25 min.

Average Fixed Time Delay = 30 min./day

MACHINE RATE CALCULATIONS

Machine rate calculations are a common method of making comparisons in costs between machine alternatives. These machine rates are based on list price quotes obtained for each truck as specified. Two hourly costs are developed: fixed and operating. Fixed costs are associated with hours "on the job" and included: moving time, loading time, unloading time, and associated in process delays. Operating costs are in addition to fixed costs and apply only to the moving time, both loaded and unloaded. Truck life is assumed to be four years at which time the truck is salvaged for 20% of the original purchase price.

MACHINE RATE CALCULATION FOR DESIGN BOBTAIL LOG TRUCK

Description: International SS 2574 equipped standard w/optional air jake.

Fixed Costs: 1600 hr./yr., 4 yr., 6400 hr. total

Truck Quote: $61,339   Salvage: 12,267

Average Annual Investment, AAI =

$$61339 - 12267 \frac{(4+1)}{2(4)} + 12267 = \$42,937$$

Interest (10%) Taxes-Insurance (2%) of AAI 5152 x 4 yrs.	=	20609
License and Fees 600/yr. @ 4 yrs.	=	2400
Total Depreciable Value	=	72081
Fixed Rate = 72081/6400	=	11.26
Loaded Labor	=	10.00
	=	$21.26/hr.

Operating Costs:

Repairs and Maintenance at 30% of D.V. (including tires)	=	$3.38/hr.
Fuel @$1.15/gal. No. 1 D 1.15(.0255)(230)	=	$6.74/hr.
Total Operating	=	$10.12/hr.

MACHINE RATE CALCULATION FOR DESIGN TANDEM AXLE LOG TRUCK

Description: Internatioal SS 2574 equipped standard w/optional C NTC 270, T313 9 speed, air, jake.

Fixed Costs: 1600 hr./Yr., 4 yr., 6400 Hr. Total

Truck Quote: $78,312 Salvage: 15,662

Average Annual Investment, AAI =

$$78312 - 15662 \frac{(4 + 1)}{2\ (4)} + 15662 = \$54,818$$

Interest (10%) Taxes-Insurance (2%) of AAI 6578/yr. x 4 yr.	=	26,312
License and Fees $800/yr. x 4 yrs.	=	3,200
Total Depreciable value	=	92,162
Fixed Rate = 92,162/6400	=	14.40
Loaded Labor	=	10.00
		$24.40/hr.

Pony Trailer + $1.60/Hr.

Operating Costs:

Repairs and Maintenance @ 35% D.V. (including tires)	=	5.04/hr.
Fuel @ $1.15/gal. No. 1 D 1.15 (.0255) (270)	=	7.92/hr.
Total Operating	=	$12.96/Hr.

MACHINE RATE CALCULATION FOR DESIGN TRIAXLE LOG TRUCK

Description: International SS 2574 equipped as standard w/optional C NTC 300 T194 9 speed, airlift axle, air, jake.

Fixed Costs: 1600 hr./yr., 4 yr., 6400 hr. total

Truck quote $81,265 Salvage: $16,253

Average Annual Investment, AAI =

$$81{,}265 - 16{,}253 \frac{(4 + 1)}{2\ (4)} + 16{,}253 = \$56{,}900$$

Interest (10%) taxes-insurance (2%) of AAI $6828/yr. x 4yrs.	=	27,312
License and fees $800/yr. x 4 yrs.	=	3,200
Total Depreciable value	=	95,524
Fixed Rate = 95,524/6400	=	14.93
Loaded Labor	=	10.00
		$24.93/hr.

Operating Costs:

Repairs and maintenance at 40% D.V. (including tires)	=	5.97/hr.
Fuel @ $1.15/gal. No. 1 D 1.15 (.0255)(300)	=	8.80/hr.
Total Operating	=	$14.77/hr.

MACHINE RATE CALCULATION FOR DESIGN TRACTOR SEMI TRAILER LOG TRUCK

Description: Kenworth K-900 equipped w/3406 CAT 350, Pitts double bunk tandem trailer.

Fixed Costs: 1600 hr./yr., 4 yr., 6400 hr. total

Truck Quote	$89,600		
Trailer	8,000		
	$98,400	Salvage:	19,680

Average Annual Investment, AAI =

$$98400 - 19680 \frac{(4 + 1)}{2(4)} + 19680 = \$68,880$$

Interest (10%), taxes & insurance (2%) of AAI 8265/yr. x 4 yrs.	=	33,060
License and fees 1000/yr. x 4 yrs.	=	4,000
Total Depreciable Value	=	115,780
Fixed Rate = 115,780/6400	=	$18.09/hr.
Loaded labor	=	10.00/hr.
fixed + labor	=	$28.09/hr.
w/setout trailer	+	$1.60/hr.

Operating Costs:

Repairs and maintenance at 40% D.V. (including tires)	=	$7.23/hr.
Fuel @ $1.15/gal. 1.15 (.0255)(350)	=	10.26/hr.
Total Operating	=	$17.49/hr.

PROJECT CONSTRUCTION COSTS

The roading project which was selected for this case study comparison has the following characteristics:

1) Total length = 7.52 miles
2) Accesses over 5200 acres
3) Terrain is characteristically rough, i.e., rocky with bouldery drains, steep side slopes
4) Has sections of reconstruction and construction
5) The traffic service level (C) (USFS 1982) will remain the same for all design trucks
6) The basic cross section of the road includes ditch and culvert drainage, and 2" of crushed aggregate surfacing.

The most efficient road designs are those that utilize design techiques which best fit the construction requirements of a segment of road. Generally, the more difficult and costly the construction of a road segment the more efficient it is to utilize sophisticated and controlled design techniques. On this project four different design techniques were used and specified in the construction contract. These techniques and their summary by mileage is as follows:

A.	Construction by the hour (equipment rental)	1.45 miles
B.	Construction by the mile	1.09 miles
C.	Construction by the station	1.07 miles
D.	Construction by the cubic yard of excavation	3.91 miles

The road design process segments the construction requirements into various items of work, estimates the quantity of each, and applies a per unit cost to arrive at the total cost for each design. The following tables list the quantitites and costs for the case study road designed for the various design vehicles. The per unit costs are those which were actually bid by the successful road contractor.

Table 1

USDA (Forest Service) Region

SUBPROJECT ESTIMATE

02/09/84

IFB NUMBER PROJECT :
SUB PROJECT(1) :16.5' BOBTAIL
DISTRICT COUNTY TERRAIN TYPE :MTN.

******** ENGINEER'S ESTIMATE ********

PAY ITEM	ITEM DESCRPTION	MM	UNIT	QUANTITY	ENGRS ESTIMATE	TOTAL
201(01)1-4	CLEARING & GRUBBING SLASH TREATMENT 1 OR 4	DQ	ACRE	21.23	1000.00	21230.00
201(02)1-4	CLEARING AND GRUBBING SLA SH TREATMENT 1 OR 4	DQ	STA	56.57	30.00	1697.10
201(04)1	CLEARING & GRUBBING SLASH TREATMENT 1	DQ	L.S.	1.00	1500.00	1500.00
203(01)	EXCAVATION - PLACEMENT METHOD 1	DQ	C.Y.	40349.00	4.00	161396.00
203(06)1	EXCAVATION - PLACEMENT METHOD 1	DQ	STA	56.57	150.00	8485.50
203(07)1	EXCAVATION - PLACEMENT METHOD 1	DQ	MILE	1.10	5000.00	5500.00
203(08)1	BORROW EXCAVATION PLACEMENT METHOD 1	DQ	C.Y.	3500.00	2.50	8750.00
204(02)	HAY OR STRAW BALES FOR E.& P. CONTROL	AQ	EA	184.00	5.00	920.00
204(05)B	TEMP. SEEDING & MULCH FOR E.& P. CONTROL	DQ	ACRE	2.32	795.00	1844.40
206A(04)	BEDDING MATERIAL	DQ	TON	117.00	9.00	1053.00
304(11)A-25	CRUSHED AGGREGATE (GRADE #25) CMPCT A	AQ	TON	4716.00	8.54	40274.64
601(01)	MOBILIZATION	LSQ	L.S.	1.00	5000.00	5000.00
603(05)18	18" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	3250.00	14.00	45500.00
603(05)24	24" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	120.00	16.00	1920.00
603(05)30	30" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	98.00	20.00	1960.00
603(05)36	36" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	30.00	24.00	720.00
603(05)42	42" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	158.00	28.00	4424.00
603(05)72	72" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	44.00	50.00	2200.00
607(03)	GATE-METAL TYPE-BAR SIZE- 14'6" '	AQ	EA	2.00	800.00	1600.00

USDA (Forest Service) Region

SUBPROJECT ESTIMATE

02/09/84

IFB NUMBER : PROJECT :
SUB PROJECT(1) : 16.5 BOBTAIL
DISTRICT COUNTY TERRAIN TYPE : MTN.

******** ENGINEER'S ESTIMATE ********

PAY ITEM	ITEM DESCRPTION	MM	UNIT	QUANTITY	ENGRS ESTIMATE	TOTAL
625(13)	SEEDING HYDRAULIC OR DRY M. W/ MULCH	DQ	ACRE	23.86	795.00	18966.70
637(04)	SMALL CRAWLER TRACTOR WITH DOZER & WINCH	DQ	HR.	90.00	50.00	4500.00
637(05)	MOTOR GRADER	DQ	HR.	16.00	50.00	800.00
637(09)	LARGE DUMP TRUCK	DQ	HR.	16.00	25.00	400.00
637(13)	TRACK MOUNTED END LOADER	DQ	HR.	16.00	55.00	880.00

SUB PROJECT(1) TOTAL $ 341,523.34

PROJECT TOTAL $ 341,523.34

Table 2

USDA (Forest Service) Region

SUBPROJECT ESTIMATE

02/09/84

IFB NUMBER : PROJECT :
SUB PROJECT(1) : 23' TRIAXLE
DISTRICT : TERRAIN TYPE : MTN.

******** ENGINEER'S ESTIMATE ********

PAY ITEM	ITEM DESCRPTION	MM	UNIT	QUANTITY	ENGRS ESTIMATE	TOTAL
201(01)1-4	CLEARING & GRUBBING SLASH TREATMENT 1 OR 4	DQ	ACRE	21.26	1000.00	21260.00
201(02)1-4	CLEARING AND GRUBBING SLASH TREATMENT 1 OR 4	DQ	STA	56.57	30.00	1697.10
201(04)1	CLEARING & GRUBBING SLASH TREATMENT 1	DQ	L.S.	1.00	1500.00	1500.00
203(01)	EXCAVATION - PLACEMENT METHOD 1	DQ	C.Y.	40432.00	4.00	161728.00
203(06)1	EXCAVATION - PLACEMENT METHOD 1	DQ	STA	56.57	150.00	8485.50
203(07)1	EXCAVATION - PLACEMENT METHOD 1	DQ	MILE	1.10	5000.00	5500.00
203(08)1	BORROW EXCAVATION PLACEMENT METHOD 1	DQ	C.Y.	3500.00	2.50	8750.00
204(02)	HAY OR STRAW BALES FOR E.& P CONTROL	AQ	EA	184.00	5.00	920.00
204(05)B	TEMP. SEEDING & MULCH. FOR E.& P CONTROL	DQ	ACRE	2.32	795.00	1844.40
206A(04)	BEDDING MATERIAL	DQ	TON	133.00	9.00	1197.00
304(11)A-25	CRUSHED AGGREGATE (GRADE #25) CMPCT A	AQ	TON	4819.00	8.54	41154.26
601(01)	MOBILIZATION	LSQ	L.S.	1.00	5000.00	5000.00
603(05)18	18" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	3316.00	14.00	46424.00
603(05)24	24" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	120.00	16.00	1920.00
603(05)30	30" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	106.00	20.00	2120.00
603(05)36	36" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	30.00	24.00	720.00
603(05)42	42" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	164.00	28.00	4592.00
603(05)72	72" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	44.00	50.00	2200.00
607(03)	GATE-METAL TYPE-BAR SIZE- 14'6" '	AQ	EA	2.00	800.00	1600.00

USDA (Forest Service) Region

SUBPROJECT ESTIMATE

02/09/84

IFB NUMBE. : PROJECT :
SUB PROJECT(1) : 23' TRIAXLE
DISTRICT : COUNTY : TERRAIN TYPE : MTN.

******** ENGINEER'S ESTIMATE ********

PAY ITEM	ITEM DESCRPTION	MM	UNIT	QUANTITY	ENGRS ESTIMATE	TOTAL
625(13)	SEEDING HYDRAULIC OR DRY M. W/ MULCH	DQ	ACRE	23.89	795.00	18992.55
637(04)	SMALL CRAWLER TRACTOR WITH DOZER & WINCH	DQ	HR.	90.00	50.00	4500.00
637(05)	MOTOR GRADER	DQ	HR.	16.00	50.00	800.00
637(09)	LARGE DUMP TRUCK	DQ	HR.	16.00	25.00	400.00
637(13)	TRACK MOUNTED END LOADER	DQ	HR.	16.00	55.00	880.00

SUB PROJECT(1) TOTAL $ 344,184.81

PROJECT TOTAL $ 344,184.81

Table 3

USDA (Forest Service) Region

SUBPROJECT ESTIMATE

02/09/84

IFB NUMBER : PROJECT :
SUB PROJECT(1) : 14' X 32' TRACTOR TRAILOR
DISTRICT COUNTY : TERRAIN TYPE : MTN.

******** ENGINEER'S ESTIMATE ********

PAY ITEM	ITEM DESCRPTION	MM	UNIT	QUANTITY	ENGRS ESTIMATE	TOTAL
201(01)1-4	CLEARING & GRUBBING SLASH TREATMENT 1 OR 4	DQ	ACRE	21.75	1000.00	21750.00
201(02)1-4	CLEARING AND GRUBBING SLASH TREATMENT 1 OR 4	DQ	STA	56.57	30.00	1697.10
201(04)1	CLEARING & GRUBBING SLASH TREATMENT 1	DQ	L.S.	1.00	1500.00	1500.00
203(01)	EXCAVATION - PLACEMENT METHOD 1	DQ	C.Y.	42388.00	4.00	169552.00
203(06)1	EXCAVATION - PLACEMENT METHOD 1	DQ	STA	56.57	150.00	8485.50
203(07)1	EXCAVATION - PLACEMENT METHOD 1	DQ	MILE	1.10	5000.00	5500.00
203(08)1	BORROW EXCAVATION PLACEMENT METHOD 1	DQ	C.Y.	3500.00	2.50	8750.00
204(02)	HAY OR STRAW BALES FOR E. & P. CONTROL	AQ	EA	184.00	5.00	920.00
204(05)B	TEMP. SEEDING & MULCH. FOR E. & P. CONTROL	DQ	ACRE	2.32	795.00	1844.40
206A(04)	BEDDING MATERIAL	DQ	TON	139.00	9.00	1251.00
304(11)A-25	CRUSHED AGGREGATE (GRADE #25) CMPCT A	AQ	TON	4926.00	8.54	42068.04
601(01)	MOBILIZATION	LSQ	L.S.	1.00	5000.00	5000.00
603(05)18	18" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	3376.00	14.00	47264.00
603(05)24	24" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	120.00	16.00	1920.00
603(05)30	30" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	126.00	20.00	2520.00
603(05)36	36" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	30.00	24.00	720.00
603(05)42	42" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	164.00	28.00	4592.00
603(05)72	72" CORRUGATED STEEL PIPE -THICKNESS- .064 "	AQ	L.F.	44.00	50.00	2200.00
607(03)	GATE-METAL TYPE-BAR SIZE- 14'6" '	AQ	EA	2.00	800.00	1600.00

USDA (Forest Service) Region

SUBPROJECT ESTIMATE

02/09/84

IFB NUMBER : PROJECT :
SUB PROJECT(1) : 14' X 32' TRACTOR TRAILOR
DISTRICT : COUNTY : TERRAIN TYPE : MTN.

******** ENGINEER'S ESTIMATE ********

PAY ITEM	ITEM DESCRPTION	MM	UNIT	QUANTITY	ENGRS ESTIMATE	TOTAL
625(13)	SEEDING HYDRAULIC OR DRY M. W/ MULCH	DQ	ACRE	24.26	795.00	19286.70
637(04)	SMALL CRAWLER TRACTOR WITH DOZER & WINCH	DQ	HR.	90.00	50.00	4500.00
637(05)	MOTOR GRADER	DQ	HR.	16.00	50.00	800.00
637(09)	LARGE DUMP TRUCK	DQ	HR.	16.00	25.00	400.00
637(13)	TRACK MOUNTED END LOADER	DQ	HR.	16.00	55.00	880.00

SUB PROJECT(1) TOTAL $ 355,000.74

PROJECT TOTAL $ 355,000.74

Of the total construction cost of each design approximately 85% proved to have variation based on differing design vehicles. The single most variable item was 203(01) Excavation by the cubic yard and this single item accounted for over 45% of the total cost of construction. The following table lists the total construction cost by design vehicle:

Bobtail Design	$341,523.34
Triaxle Design	$344,184.81
Tractor Semi Trailer Design	$355,000.74

TIMBER SALE HAUL COSTS

The timber sale accessed by this roading project will consist of 106 acres of regeneration with a total estimated gross volume of 1.7 MMBF.

Of this estimated total gross volume approximately 40% will be in sawtimber. The following calculations convert the sale volume to total weight by product:

$$(1700\ \text{MBF})(.40)(12900\ \#/\text{MBF}) = 8{,}772{,}000\#\ \text{sawtimber}$$

$$(1700\ \text{MBF})(.60)\left(\frac{\text{MBF}}{.77\ \text{CCF}}\right)(7300\#/\text{CCF}) = 9{,}670{,}100\#\ \text{pulpwood}$$

The following table lists the road log, average traveled miles per hour, and round trip minutes for the actual sawtimber and pulpwood haul routes:

SAWTIMBER HAUL ROUTE

Route	Classification	One Way Mileage	Average MPH	Roundtrip Minutes
45	Forest Development Road	9.7	7	166.0
602	State Secondary, Paved	1.6	20	9.6
122	State Primary, Paved	3.2	35	5.9
501	State Primary, Paved	0.4	35	1.4
Mill	Secondary, Gravel	0.2	15	1.6
		15.1 miles		184.5 Min/R.T.

PULPWOOD HAUL ROUTE

Route	Classification	One Way Mileage	Average MPH	Roundtrip Minutes
45	Forest Development Road	9.7	7	166.0
602	State Secondary, Paved	1.6	20	9.6
122	State Primary, Paved	3.2	35	5.9
501	State Primary, Paved	1.2	35	4.1
Mill	Secondary, Paved	0.4	20	2.4
		16.1 miles		188.0 Min/R.T.

Haul Cost Computations

Utilizing the above haul routes, machine rate calculations, and round trip elements already presented the daily operating cost can be computed. First the number of loads/day is determined based on a maximum of 12 fixed hours/day. The total daily fixed hours and operating hours are then computed and the respective machine rates applied to get the total daily cost.

TOTAL $/DAY

	Bobtail	Tandem	Tandem W/Pony	Triaxle	Tractor w/set out Semi Trailer
Payload, LBS.	18400	29100	49100	37100	51200
Load, Min.	23	34	64	42	25
Unload, Min.	20	20	20	20	20
Sawtimber Haul					
Total Min./R.T.	228	239	269	247	230
Loads/Day	3	2	2	2	3
Fixed Hr./Day	11.90	8.47	9.47	8.73	12.00
Operating Hr./Day	9.25	6.17	6.17	6.17	9.25
$/Day	$346.60	$286.63	$326.18	$308.77	$518.06
Pulpwood Haul					
Total Min./R.T.	231	242	272	250	233
Loads/Day	2	2	2	2	2
Fixed Hr./Day	8.20	8.57	9.57	8.83	8.27
Operating Hr./Day	6.27	6.27	6.27	6.27	6.27
$/Day	$237.78	$290.37	$330.08	$312.74	$355.20

By utilizing the previously determined forest product volumes to be hauled and assuming that the sale will be serviced with 7 landings the following table summarizes the total haul costs for the given sale.

TOTAL HAUL COST BY DESIGN VEHICLE

	Bobtail	Tandem	Tandem w/Pony	Triaxle	Tractor w/setout Semi Trailer
Sawtimber Haul					
Total Days	158.9	150.7	89.3	118.2	57.1
Total Cost	$55075	$43195	$29128	$36497	$29581
Pulpwood Haul					
Total Days	262.8	166.2	98.5	130.3	94.4
Total Cost	$62489	$48259	$32513	$40750	$33531
Landing Cost	1050	1050	1575	1050	2625
Total Haul Cost	$118614	$92504	$63216	$78297	$65737

TOTAL COST COMPARISONS

Total cost comparison between alternative roads would include haul costs, maintenance costs and construction costs. Haul costs and construction costs have already been presented. Maintenance costs for the various road designs will be the same since the traffic service level and basic cross section have been held constant. Since there is no difference in maintenance costs they will not be included in the cost comparison.

The construction cost of the Tandem Design Truck will be assumed to fall midway between that of the Bobtail and the Triaxle Truck. This assumption is based on the fact that there was little difference between Bobtail and Triaxle design costs, and the Tandem has a wheelbase which falls midway between the two trucks.

The construction cost of the Tandem Truck with the pony trailer will be assumed to be the same as the design Triaxle cost. The reason for this assumption is that the equation which generates curve widening in the computer aided road design program utilizes a combined wheelbase length (USFS 1982). This combined wheelbase for a stinger type truck is:

$$L = \sqrt{L_1^2 + L_3^2 - L_2^2}$$

Where: L = Combined wheelbase utilized in equation
L_1 = Wheelbase of tractor
L_2 = Length of stinger
L_3 = Length from hitch point to trailer wheels

For the Tandem Truck with Pony Trailer this is:

$$L = \sqrt{20^2 + 12^2 - 9^2} = 21.5 \text{ FT.}$$

This is approximately the same wheelbase as the 22 FT. wheelbase of the Triaxle and the design quantitites would be the same.

The cost comparison of the various designed roads will be over a 20 year period . This will allow for five hauling cycles (i.e., 5 yr. entry period). The present net cost (PNC) of the alternatives will be determined using a four percent interest rate as follows:

$$PNC = \text{Construction Cost} + \text{Haul Cost} \left(P/F_{N=1} + P/F_{N=5} + P/F_{N=10} + P/F_{N=15} + P/F_{N=20}\right) \quad \text{Where } i = 4\%$$

$$PNC = \text{Construction Cost} + \text{Haul Cost} \left(.96 + .82 + .68 + .56 + .46\right)$$

$$PNC = \text{Construction Cost} + \text{Haul Cost} \ (3.48)$$

The following table lists the present net costs for the various design trucks:

	Bobtail	Tandem	Tandem w/Pony	Triaxle	Tractor w/set out Semi Trailer
Construction Costs	341,523	342,854	344,185	344,185	355,000
Haul PNC	412,777	321,914	219,992	272,474	228,765
Total Cost	754,300	664,768	564,177	616,659	583,765

SUMMARY AND CONCLUSIONS

The results of this case study show that the least expensive design vehicle was the **Tandem straight truck pulling a pony trailer.** Its effective wheelbase of only 21.5 feet and its payload of 49100# combine to provide the most efficient combination. This combination vehicle is not at present very common practice for western Virginia loggers. We need more work in this area to verify these results.

The effect of design vehicle on construction costs was relatively minor. This is true despite the fact that this was some of the roughest most expensive forest development road built in the area. Unit costs on the 203(01) pay item, excavation by the cubic yard, in this project were \$4.00/yd. , average costs per this pay item are close to \$2.00/yd. . In this study construction costs varied approximately 4 percent from the smallest to the largest design vehicle. Had this been average unit costs this variation would have been 3.6 percent. Therefore, selection of design vehicles does not have a significant impact on construction costs.

The effect of design vehicle on haul costs was significant. By constraining the design vehicle to the smallest truck haul costs were increased approximately 90 percent over that of the most efficient truck.

ECONOMIC ANALYSIS OF BROAD-BASED DIPS VERSUS CONVENTIONAL DRAINAGE STRUCTURES ON FOREST ROADS -- PRELIMINARY RESULTS

by

Ronald W. Eck
Randall S. Burks
Perry J. Morgan
Ross A. Phillips

ABSTRACT

Preliminary results of an on-going study conducted to address the issue of broad-based dips versus conventional drainage structures were presented. A decision-making framework was developed that can be used as a general guide to factors to consider in selecting a dip or culvert in a particular application. Specific questions which the engineer should address relative to soils/ geology, hydrology, construction, maintenance and road user factors were identified. The experimental design to be used to collect detailed data at a number of field sites in the Monongahela National Forest in West Virginia was outlined.

ECONOMIC ANALYSIS OF BROAD-BASED DIPS VERSUS CONVENTIONAL DRAINAGE STRUCTURES ON FOREST ROADS—PRELIMINARY RESULTS

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INTRODUCTION

Background and Problem Statement

To remain usable, logging roads must be adequately drained. Several types of drainage devices are used for controlling water flow on logging roads. Probably the most common type is the culvert. A second type, the broad-based dip, can be used instead of culverts for cross drainage where no intermittent or permanent streams are present. Currently, there is some controversy among foresters regarding the relative benefits and costs of each of these devices.

One school of thought suggests that metal culverts are superior for most drainage needs. The initial cost of culverts is high compared with simple drainage devices but they have relatively long lifetimes, require relatively little maintenance and are essentially unnoticed by road users.

Other individuals promote broad-based dips because of their several advantages. These promoters say that when properly installed, dips have low maintenance costs and do not increase wear on vehicles or reduce hauling speed. The biggest disadvantage of broad-based dips is that equipment operators need special training before being able to construct dips properly. Thus, dips are often not built according to the intended specifications.

Design criteria have been established for both broad-based dips and culverts, although actual device dimensions and other details may vary from one region to another. Kochenderfer (1970), Rothwell (1971), Haussman and Pruett (1978), Gardner, et al. (1973) and Hewlett, et al. (1979) presented general guidelines for the design and use of both dips and culverts. A number of other articles have appeared in the engineering and forestry literature discussing the relative advantages and disadvantages of these two drainage de-

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vices. Hafterson (1973), Megahan (1977) and Cook and Hewlett (1979) identified situations in which improper construction of broad-based dips could create safety or operational problems. For the most part, however, the information found in the literature was of a general and, sometimes, subjective nature. Little, if any, quantitative benefit/cost data or economic analyses are available to permit an objective comparison to be made between dips and culverts. A comprehensive literature review revealed only one reference to costs of constructing broad-based dips (Koger, 1978).

Based on this literature review and discussions with forest road designers, builders and users in the Appalachian Region, it became apparent that while dips and culverts each have their place as a drainage device on low standard roads, there are certain conditions where one is more appropriate than the other. There is a need to determine objectively, using actual field data and an engineering economic analysis, under what conditions conventional metal culverts are more appropriate than broad-based dips on logging roads in the Appalachian Region.

Study Objectives

A research project was undertaken to answer the question just raised. To address the overall goal, several specific objectives were established:

- To conduct a literature review to acquire quantitative information relative to the use and performance of broad-based dips and conventional metal culverts on forest roads.
- To identify, based on the literature review and a field survey, specific factors which need to be considered in the decision to use culverts or dips.
- To develop and carry out an experimental design to collect detailed data at a number of field sites in the Appalachian Region to quantify the construction, maintenance, road user and other measurable costs associated with dips and culverts.
- To conduct an economic analysis using the aforementioned data, to determine specific conditions under which culverts and/or broad-based dips should be installed.

Although project effort is currently concentrating on the third objective, at the time of writing only the first two objectives have been accomplished. Thus, this paper focuses primarily on identifying and discussing factors to be considered in selecting type of drainage device for a particular application. Future work to be accomplished will then be outlined briefly; additional details will be provided at the symposium presentation.

THE DECISION: DIP OR CULVERT?

Decision-Making Framework

At present, no distinct set of guidelines exist which engineers or foresters can apply in making a decision about whether to use metal pipe culverts or broad-based dips to handle cross drainage situations on logging roads. Development of guidelines to assist in selecting the most appropriate type of cross drainage was one of the objectives of this research. To develop such guidelines, the factors involved must be known. Based on the literature review and field survey, those factors which need to be considered in the decision to use culverts or broad-based dips were identified. To establish a convenient decision-making framework, it was decided to group the factors into several major categories. Figure 1 presents a preliminary decision-making framework that can be used as a general guide to factors to consider in selecting a broad-based dip or conventional metal culvert in a particular application. The next section of the paper raises specific questions which the engineer should address about each of the factors. Note that several categories in the framework include some factors which can be quantified in terms of cost and others which cannot be quantified readily. This paper addresses primarily the qualitative decision-making factors. Complete data on the quantitative factors will not be available until the data to be acquired in the field study have been collected and analyzed.

Factors to Consider

The preceding section presented a preliminary guide that could be used as a checklist of factors to consider in selecting cross drainage type on logging roads. This section provides more specific information about the factors listed in the framework.

Soils/Geology - - Perhaps the most important factors in the dip versus culvert decisions are the geological and soils characteristics of the cross drainage location. Information on the type and orientation of the underlying bedrock should be acquired. Certain formations, for example sandstones, may transmit significant amounts of water. Depending on the dip of the bedrock, water may be present at points on the road where it was not anticipated. In such circumstances, ditch and culvert systems are preferable to broad-based dips. An exception to this would be a road passing through rock. In ditch and culvert systems this situation would be expensive; broad-based dips might be used to reduce costs.

The erodibility of a soil is of critical importance. In soils that erode readily, pipe culverts should be installed instead of dips. Similarly, on fills greater than 3 feet high, ditches and culverts should be used since dips tend to exacerbate erosion problems. Soil acidity must also be avaluated. Where there is an acid problem, culverts will have shorter lifetimes than they would in a less acid environment. Under these conditions, dips may be the preferred drainage structure.

Hydrology - - This category relates to factors such as annual precipitation, ground water table, and watershed characteristics. Culverts are necessary when perennial streams, intermittent streams with well-defined channels and

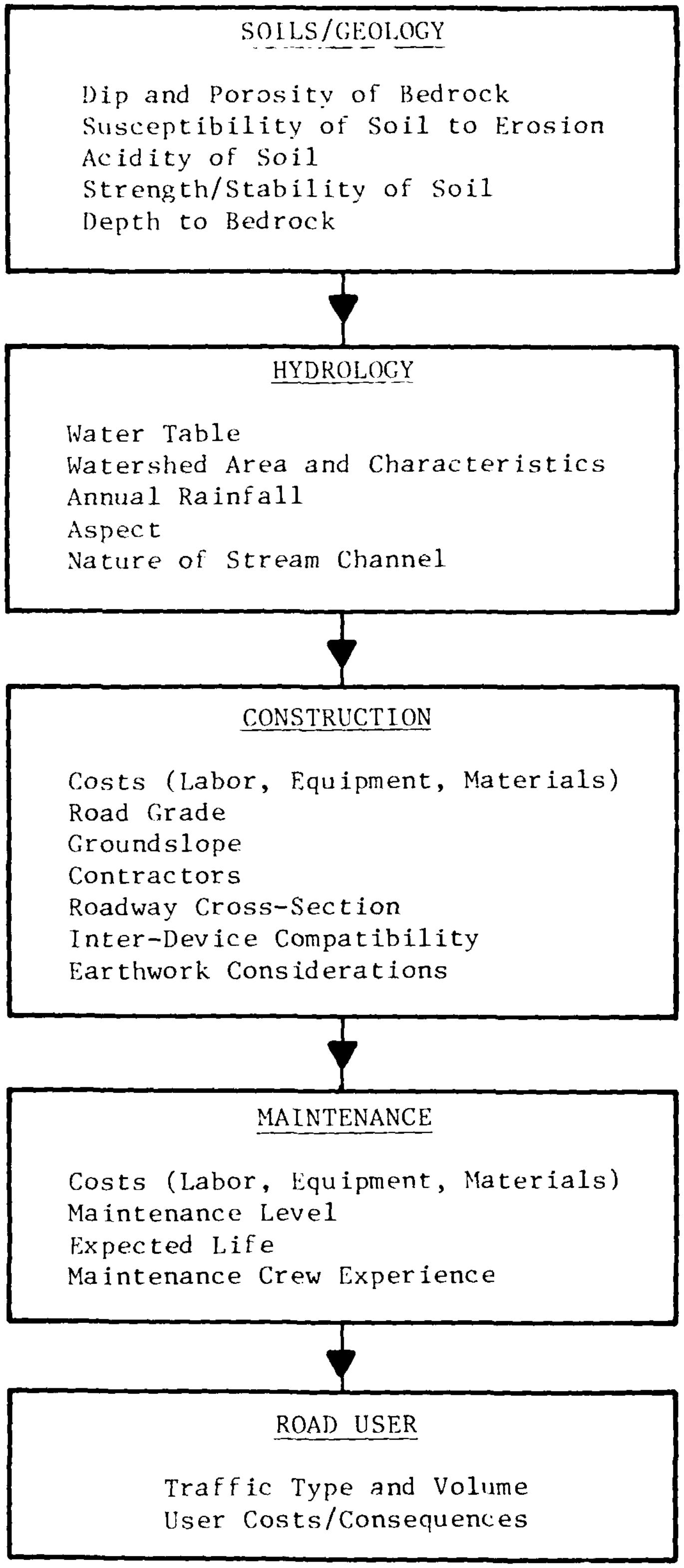

Figure 1. General Guide of Factors to Consider in Selection of Broad-Based Dips or Ditches and Culverts.

major groundwater seepages are encountered. In areas where a high water table exists as evidenced by springs and seeps, culverts should be used rather than dips. In this regard, the aspect of the road is important. On a road with a north aspect and high water table, the presence of significant quantities of water may virtually rule out the use of dips. However, for a road with a south aspect, due to the drying effect of solar radiation, dips should at least be considered as a possibility.

Rainfall can also be an important factor. Within a forest, roads on ridges and other areas receiving high annual rainfall amounts should have ditches and culverts installed. For roads in those areas receiving lesser amounts of rainfall, dips should be considered as a possibility. The size of the watershed area drained by a particular device must also be considered. Dips are usually preferred over culverts for roads "high up" in a watershed where the volume of flow is relatively small. The converse of this statement is also true, i.e., for roads near the mouth of a watershed, culverts are preferred over dips since they are better able to handle the larger amounts of water expected.

Construction - - Based on experience acquired in a number of eastern forests, certain situations have been identified where dips should not be constructed. In general, where the gradient of the road exceeds 8 percent, culverts should be used instead of dips. If the groundslope is greater than 35 percent, culverts should be used exclusively.

An issue that must be resolved early in the design process is the desires and capabilities of the road builders, e.g. contractors. Some firms, because of lack of skilled labor cannot construct dips as specified. Others will simply not build dips due to problems they perceive to be associated with dips. As part of this research, a telephone survey was made of four contractors who had built logging roads in the Monongahela National Forest in West Virginia. All four indicated that, given a choice, they would prefer to install culverts rather than dips due to difficulties in constructing dips.

Although engineers and foresters seem to agree that the initial cost of dips is less than the cost of metal culverts, only one reference could be found in the published literature comparing the costs of the two devices (Koger, 1978). Thus, one purpose of the above-mentioned contractor survey was to obtain information on the costs associated with constructing broad-based dips since there may be wide variations in soil types and earthwork quantities involved. However, certain general trends emerged from the limited contractor survey. Construction of a dip typically requires two persons and a small bulldozer; time required ranges from 2 1/2 to 4 hours per dip. Installed costs (as of February 1984) reported by contractors ranged from $250 to $300 per dip.

Survey results verified that under comparable conditions, culverts have higher initial costs ($460 to $520 per device) than dips. This is mainly due to greater labor and equipment costs. Usually 3 persons, a backhoe and a hand tamper are required to install a culvert; typical installation time is 4 hours. Additional data are still being acquired from other contractors. Thus, there is the possibility that the quantities presented here may change slightly when final results are tabulated.

Maintenance - - Both dips and culverts require periodic maintenance to ensure that the devices remain in working order. Maintenance crews are generally familiar with the procedures for maintaining the traditional ditches and culverts. Training and experience of equipment operators must be considered in the maintenance of dips. Where maintenance presents a problem, culverts should be favored over dips.

The expected life of the road is another consideration. The maintenance requirements of both dips and culverts should be evaluated before reaching a decision. If the road will be "put to sleep" in the future, dips may be preferred since they require less maintenance than culverts in this situation.

Maintenance costs are obviously an important factor in decision-making. To date, however, no published maintenance costs comparing culverts with broad-based dips have appeared in the literature. In this study, maintenance data will be acquired to permit a determination of typical maintenance costs associated with each drainage device. At this time, however, these maintenance cost data are not available for publication.

Road User - - The volume of traffic and type of vehicles traversing a road can influence the drainage device selected. Culverts should be used exclusively on roads open to automobile traffic. This is because low ground clearance vehicles may have trouble negotiating broad-based dips. Similarly, dips should not be used on paved roads.

It is recommended that dips not be installed on horizontal curves. When wet, the roads become slippery (especially in the silty-clay soils of the Appalachian Region) creating a safety hazard on the outsloped curve. Another potential problem has been noted in some forests where single-unit hauling trucks with high loads are common. There is the possibility that the vehicle could overturn as it negotiates the outsloped curve. If tractor-trailer units are expected on the raod, dip dimensions should be checked to be sure the dip can be traversed. If not traversible, culverts will have to be used.

Culverts could be said to be "invisible" to the road user in that they can go unnoticed by vehicle operators. However, the associated ditch and headwall can pose hazards to vehicles that stray from the roadway. In contrast, dips have a definite impact on the road user. Most vehicles will have to slow down to negotiate the rather abrupt change in grade. Furthermore, the vehicle will undergo some twisting action which in extreme cases could cause damage to the vehicle and/or the load. The cost of vehicle damage and wear, time loss and additional fuel consumption attributable to dips must be considered in comparing the two drainage devices.

This section has presented a partial overview of the factors that must be considered in selection of a dip or culvert for a particular drainage situation on logging roads. As was noted, the work reported here has not been completed. Efforts continue to acquire construction, maintenance and road user cost data for both types of drainage devices. When appropriate costs have been developed, a decision-making flow chart incorporating the qualitative factors discussed here will be prepared. This should be a useful tool for engineers or foresters concerned with selection of drainage devices on logging roads.

FUTURE WORK

Experimental Design

Currently, an experimental design is being prepared for a field study in Monongahela National Forest involving data collection at a number of sites. The experimental plan will be formulated to that the effects of variables, such as those discussed in the preceding section, which influence dip and culvert construction, performance and maintenance can be assessed.

A two part experimental plan is envisioned. One part will involve detailed study of a limited number of road sections containing both dips and ditches with culverts. Interest here will focus primarily on road user aspects. Speeds and travel times of vehicles traversing the drainage devices will be collected. Evidence of accidents or vehicle damage caused by the drainage features will be sought. Truck drivers will be interviewed to determine their attitudes and perceptions about broad-based dips.

The second part of the experimental plan involves a less detailed study of a larger number of road links. An attempt will be made to select sites that are similar in some respects (e.g., aspect or soil type) but different in others (e.g., rainfall or soil acidity) in order to reduce the influence of certain variables. Subjective evaluations will be made of how well dips and culverts are performing in each of various circumstances. Work on this aspect of the project is currently in progress; more detailed discussion of the subjective evaluations will be presented at the symposium.

Economic Analysis

Using the cost data currently being acquired and the road user and device performance information to be collected in the task described above, an economic analysis will be performed. The analysis will involve comparisons of construction, maintenance and road user costs between the two types of drainage devices. The findings of the economic analysis will be combined with the other (non-quantifiable) conclusions drawn from the field study. The result will be identification of those conditions where conventional metal culverts are more appropriate than broad-based dips for intermittent cross flows on Appalachian logging roads.

CONCLUDING REMARKS

Discussions with engineers and foresters working in the areas of logging road design, construction or maintenance reveal two fairly distinct schools of thought about the benefits and costs of broad-based dips and conventional culverts. Preliminary results of a study undertaken to examine this issue have been presented. It became apparent early on that the topic was more complex than first imagined. Neither dips nor culverts are a panacea for drainage problems on logging roads; each device has its unique strengths and limitations. However, certain situations exist where one device may be more appropriate and more cost-effective than the other. We have documented some of these conditions and have presented a decision-making framework to assist engineers or foresters to select the appropriate drainage device for a particular application. These results are preliminary and therefore subject to change based on the forthcoming field study and economic analysis.

ACKNOWLEDGMENTS

This research was supported by funds provided by the U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. Special appreciation is expressed to the numerous individuals at the Monongahela National Forest headquarters for their cooperation and assistance in carrying out this study. The contractors who participated in the cost survey deserve thanks for giving freely of their time and expertise.

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FOREST ROAD EROSION
IN THE OUACHITA MOUNTAINS

by

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ABSTRACT

The quantity and disposition of sediments eroded from four segments of an established forest road in the Ouachita Mountains of Arkansas were determined for each storm event that occurred between June 1,1982 and May 31, 1983. Road segments (average length--330 ft) were defined as the centerline distance from a vertical curve crest to the first cross-drain culvert, a mechanism for dispersing water from the upslope ditch onto vegetated side-slopes below the road. Slope gradients of the segments ranged from 1% to 7% and averaged 4%. Measurements at the outlet of each cross-drain were total discharge volumes, discharge rates and peaks, deposited sediment, suspended sediment, and downslope movement of deposited sediments. Concurrent measurements included sediment concentrations in a stream flowing parallel to and about 150 ft. below the road and rainfall amounts, durations, and intensities. Thirty-six storm events produced annual sediment yields from the crowns, ditches, and back-slopes of the road segments ranging from 7 t/ac to 34 t/ac (average 23 t/ac). One storm, which produced 13 in. of rainfall in 24 hr., accounted for about half of the total annual sediment yields. Deposited sediments, most of which moved only a short distance downslope, constituted about 41% of total sediment yields. Close inspection of the slopes below the cross-drains revealed that, for all but the largest storms, much of the suspended sediments was trapped on-site as the road water infiltrated or was ponded in surface depressions. The only exception was a culvert that emptied into a natural ephemeral drainage. Roadbed slope gradient accounted for most of the variation in sediment losses among road segments. Measured rates of soil erosion were 1200% less than previously reported predicted rates.

FOREST ROAD EROSION IN THE OUACHITA MOUNTAINS

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Erosion of road surfaces, ditches, and cut slopes is often the major source of sediment on forest lands (Patric 1976, EPA 1984). Poorly designed, constructed and maintained roads are especially vulnerable to erosion (Hoover 1950, Weitzman and Trimble 1952, Hornbeck and Reinhart 1964, and Kochenderfer and Aubertin 1975). However, several studies have concluded that methodologies and technology are available for designing, constructing and maintaining forest roads so as to minimize erosion and sediment losses (Kochenderfer 1970, Cook and Hewlett 1979, Groves et al. 1979).

In 1979, Arkansas conducted a statewide assessment of non-point source pollution (Arkansas Dept. of Pollution Control and Ecology 1980) using a modification of the Universal Soil Loss Equation (Dissmeyer and Foster 1980). According to the assessment, the third most severe road erosion problem in the state was on the Alum Creek watershed where road erosion was estimated to be 692 tons per mile per year. Our study was initiated (1) to evaluate the accuracy of the predicted erosion rate; (2) to measure rates of erosion from road crowns, ditches, and backslopes on established roads in the Ouachita Mountains and identify factors important in road sediment production; and (3) to evaluate the capacity of the forest floor to minimize the quantity of road runoff water and eroded sediments reaching a stream course.

METHODS

Study Area

The Alum Creek watershed is located in the Ouachita Mountains of west central Arkansas (Figure 1). The upper watershed area drains into Lake Winona, a water supply reservoir for the city of

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Little Rock. About 85% of the watershed area above Lake Winona lies within the Ouachita National Forest.

The Ouachita Mountains are comprised predominantly of east-west trending ridges with elevations of approximately 2,000 ft., rising from valleys of about 750 ft. elevation. The geologic formations underlying the study area are Jackfork sandstone and Stanley shale. Soils are shallow, well drained and have formed from the weatherable shales. Surface layers are brown gravelly silt loams about 2 in. thick. Subsoils are silty clays and clays from 21 in. to 40 in. thick. The soils, mapped as the Carnisaw-Pirum-Townley Association, are clayey, mixed, thermic Typic Hapludults (U.D.S.A. Soil Conservation Service 1979). Annual precipitation, mainly in the form of rain, averages 53.3 inches (U.S. Dept. Commerce 1982).

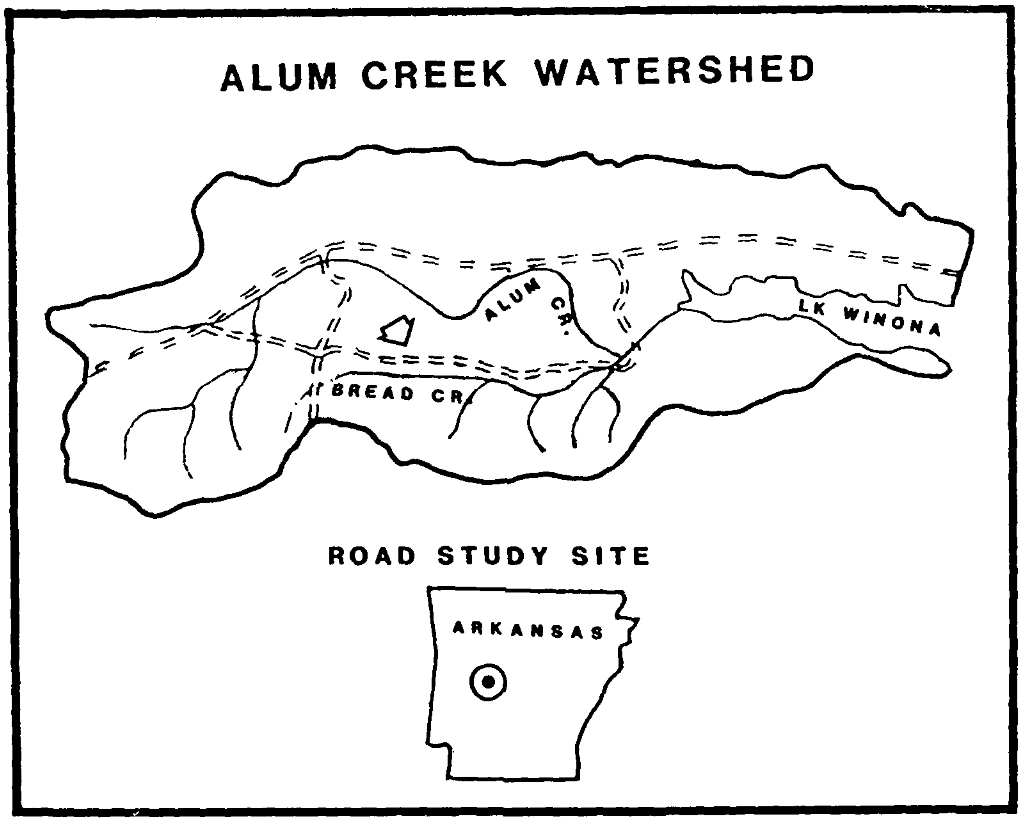

Figure 1. Location map of experimental road segments (see arrow) on the Alum Creek watershed.

The road selected for study is part of a U.S. Forest Service road network and is classified as an all-weather secondary road. It runs parallel to and about 300 ft. upslope from Bread Creek, a perennial tributary to Alum Creek. The site was specifically selected to permit measurement of road runoff and sediments and to trace their deposition and/or movement downslope to the stream. The road was constructed about 16 years ago and is maintained in accordance with U.S Forest Service standards. Cross-drain

culverts and wing-ditches divert road and ditch water onto forested sideslopes. The road receives traffic from sightseers, firewood cutters, hunters, and periodic log trucks from National Forest and industrial logging operations.

Measurements

Four road segments were selected for intensive study. The segments were chosen to provide a range of slope gradients, drainage features, and other road characteristics typical of the region. A segment was defined as the centerline distance from a vertical curve crest to the first cross-drain culvert. The length, area of cut slope and ditch, and slope gradient of each segment were measured. The area of the crown yielding flow for the inside (upslope) ditch was also determined at each segment. Segments were chosen which had a minimum of flow from upslope areas.

Sluice boxes constructed of treated plywood were placed at the outlets of cross-drain culverts to divert ditch water through 1.5 ft. precalibrated H-flumes equipped with water stage recorders. The sluices, placed at a 2% slope, also doubled as approach structures to even out flow and minimize turbulence.

Coshocton Wheel Samplers placed below the flumes extracted proportional aliquots of flow (roughly .5%) which were collected in 200 gallon covered tanks. After each storm, the sample volumes were measured and tank contents were thoroughly stirred and subsampled for analysis. Suspended sediment was determined by evaporation and reported as concentration (ppm). Total suspended sediment loss was calculated as the product of total stormflow and sediment concentration.

Removable sediment traps constructed in the sluices collected the bulk of the larger sediments and aggregates. Other sediments were deposited on the floor of the sluices behind four inch sediment baffles. After each storm all deposited sediment was weighed, subsampled for moisture content and particle size determinations, and then discharged into the flow path below the flumes. Total sediment loss was the sum of deposited (dry weight) and suspended sediment expressed as tons/acre (t/ac) of road area (crowns, ditches, and cut slopes) and tons/mile (t/mi) of road. Visual inspections of channelization, sediment movement and deposition below each flume were made periodically. The sampling equipment delayed but did not prevent sediment movement. Flow and deposited sediment were not removed or diverted from the area below the flumes and efforts were not made to artificially stabalize the impact area.

Two automatic pumping samplers were installed in Bread Creek, one at a point upstream from the study segments and another immediately downstream. Samples were collected sequentially during storm runoff events for total suspended sediment and turbidity determinations. Data from the stage-activated pumping samplers were supplemented by "grab" samples during periods when streamflow response to small storms was minimal.

RESULTS AND DISCUSSION

Road Segments

Lengths of the four road segments ranged from 308 to 357 ft. and averaged 330 ft. Mean slope gradients varied from 1% to 7% (Table 1) and total area of crown, ditch and cut slope ranged from 0.13 ac. to 0.16 ac. There was considerable variation among segments in the proportion of backslope to total area; but the other components were relatively consistent among segments (Table 1).

Table 1. Dimensions and physical characteristics of experimental road segments.

Seg. No.	Slope Gradient	Total Length	Avg. Widths Crown	Ditch	Cut Slope	Total
	%	ft.	ft.	ft.	ft.	ft.
1	7	308	8.4	6.3	6.3	21.0
2	4	335	5.6	5.0	8.8	19.4
3	6	318	5.9	5.0	10.5	21.4
4	1	357	6.2	4.6	4.6	15.4
means	4	330	6.5	5.2	7.6	19.3

	Areas Crown	Ditch	Cut Slope	Total
	ac.	ac.	ac.	ac.
1	.06	.04	.04	.14
2	.05	.04	.06	.14
3	.04	.04	.08	.16
4	.05	.04	.04	.13
means	.05	.04	.06	.14

Fill slopes below the road segments were well vegetated and virtually no bare soil was exposed. Road crown runoff that flowed to the outside edge was not channelized and generally dispersed onto vegetation or forest litter and quickly infiltrated.

Cut slopes in contrast were sometimes steep, bare and actively eroding. Upslope or inside ditches accumulated flow and sediments above cross drain culverts. With few exceptions, on the

entire road under study the potential for flow and sediment movement was limited to runoff accumulated in inside ditches.

Precipitation and Runoff

Thirty-six runoff producing storms were monitored from June 1, 1982 to May 31, 1983. It was not always possible to measure sediment yields separately for each individual storm when storms occurred in rapid succession. Precipitation for the year was 61.2 in., roughly 15% higher than the mean annual rainfall of 53.3 in. The study period included a storm event that produced 13.3 inches of rainfall during a 24-hour period. This storm exceeded the 100 year 24 hour rainfall amount (U.S. Dept. Commerce 1961).

Table 2. Annual runoff for the experimental road segments.

Seg. No.	Runoff Volume	Runoff Area-Inch	Runoff as % of Rainfall
	ft^3	in.	%
1	85,208	161	263
2	173,740	334	546
3	170,732	299	488
4	356,998	779	1272
means	196,670	393	642

Annual runoff for the four segments when expressed as depths over that road area (Table 2) exceeded annual rainfall by factors of 2.6 (Segment 1) to 12.7 (Segment 4). This indicated that not only was infiltration on the road prism negligible but that all the segments received flow from upslope forested areas. Peak discharge rates were significantly correlated with rainfall intensities (P = 0.5). Maximum peaks ranged from 1.9 to 3.7 cubic feet per second (cfs) on the four segments.

Sediment

Annual sediment losses totaled 33.7, 19.4, 32.3, and 6.8 t/ac for the four segments, respectively, (Table 3) and averaged 23 t/ac. About half the annual total resulted from the 100 year storm described above. Sediment losses expressed per unit length of road were 84.0, 43.8, 84.5 and 12.7 t/mi, and averaged 56 t/mile which was 636 t/mi less than the predicted rates reported in the statewide non-point source assessment. These results cast serious doubt on the method used to predict erosion of forest roads in the Arkansas assessment.

A substantial proportion of the total sediment load from segments 1, 2, and 3 was deposited at the outlets of cross drain culverts. Deposited sediment for the three segments comprised

64%, 26% and 32% of total sediment losses (Figure 2). Total sediment losses were virtually the same for Segment 1 and Segment 3; however, deposited sediment from Segment 1 was about twice that of Segment 3. Conversely, suspended sediment from Segment 3 was twice that of Segment 1. Segment 1 was the steepest of the

Table 3. Annual Sediment losses for the experimental road segments.

	Deposited		Suspended		Total	
Seg. No.	Tons Per Acre	Tons Per Mile	Tons Per Acre	Tons Per Mile	Tons Per Acre	Tons Per Mile
1	21.6	54.0	12.0	30.0	33.7	84.0
2	5.0	11.3	14.4	32.6	19.4	43.8
3	10.2	26.7	22.1	57.8	32.3	84.5
4	0.2	0.3	6.6	12.4	6.8	12.7
means	9.2	23.1	13.8	33.2	23.0	56.3

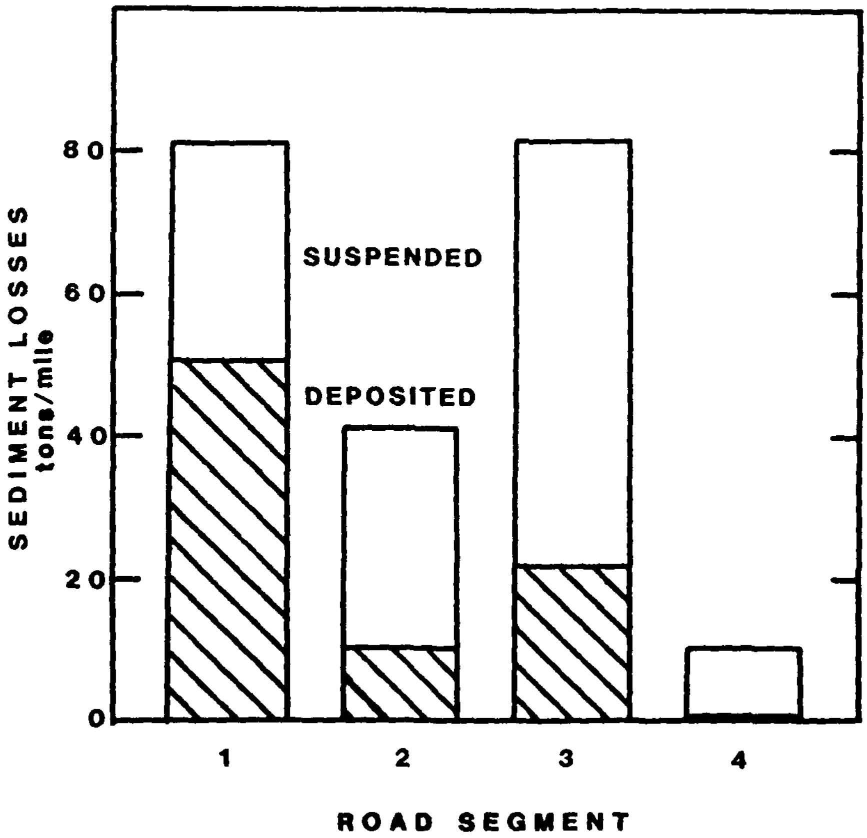

Figure 2. Suspended and deposited (cross-hatched) sediment losses (tons per mile) for the four road segments.

four sites with an average slope of 7%. The steeper gradient was conducive to greater flow velocities, steeper rising limbs of the hydrographs, and a greater capacity for carrying large sediments. However, the backslope area of Segment 3, almost twice that of Segment 1, provided more source area for sediments. Furthermore, water contributed from slopes above the road was twice as great on Segment 3 as on Segment 1 (Table 2). To enter the ditch the contributed water flowed across the relatively large bare cut slope of Segment 3 at a slump near the culvert inlet thereby providing the potential for increased erosion and transport.

The importance of slope gradient and exposed cut slope areas in the erosion of road surfaces is clearly demonstrated by comparing sediment losses from Segment 4 with the others. Segment 4 lost 6.8 t/ac (12.7 t/mi), 98% of which was suspended. The segment had a mean slope of 1% and a much smaller proportion of cut slope than the others. Perhaps even more important, its cut slopes were well covered with vegetation. Regression analysis showed that slope gradient of the road surfaces accounted for 98% of the variation in total sediment losses among segments.

The crowns of the road segments were generally well armored with naturally occurring gravel and shale; and there was little visual evidence of erosion from the crown. Based on the assumption that most sediments measured at the cross drain outlets originated in the ditches and backslopes we computed deflation rates for those surfaces (Table 4). The values ranged from a low of 0.006 in on Segment 4 to highs of .036 in on Segment 3 and 0.34 in on Segment 1.

Table 4. Annual deflation rates for the individual road segments.

Seg. No.	Annual Deflation
	in.
1	.034
2	.019
3	.036
4	.006

Regression analysis revealed that flow rates and volumes were good predictors of total sediment losses on all segments (P=.05). Deposited sediment was more closely correlated with flow

rates than was suspended sediment. Sediment concentrations were not significantly related to either flow volumes or rates.

Downslope routing of sediment to the stream was measured via direct inspection below culvert outlets and measurements and comparisons of suspended sediment in Bread Creek upstream and downstream from the road segments. Inspection of the forest floor below culvert outlets during and after storm events revealed that on three of the four segments little if any sediment laden runoff directly entered Bread Creek. Instead, most water either accumulated in depressions or infiltrated prior to reaching the stream channel. The single exception was on Segment 3 where the cross drain outlet was near an ephemeral drainage which carried the road water and its suspended load directly onto the floodplain of the stream. However, occasional depressions, heavy vegetation, and natural debris from past erosion slowed runoff velocity enough to permit sediment to be deposited before entering the stream. During flood conditions direct entry would have occurred.

Within sites, sediment losses varied with storm intensities and appeared to be influenced by the condition of the cut slope. A comparison of results from three storms on Segment 1 illustrate the relationships (Figure 3). Sediment losses varied from 31 to

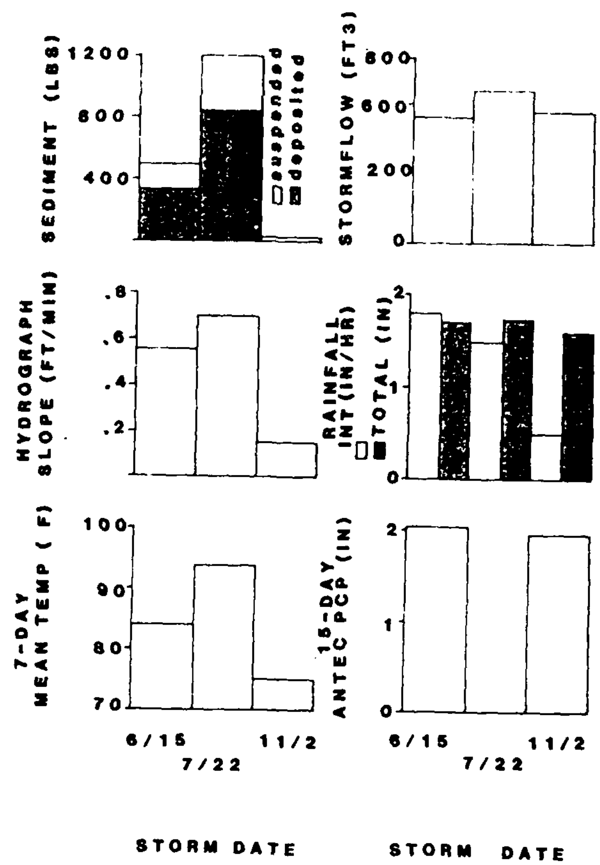

Figure 3. Comparison of storm parameters for three events on Segment 1.

1204 lbs. (3780%) while rainfall ranged from 1.60 in. to 1.73 in. (only 8%), and stormflow ranged from 549 to 666 ft^3 (21%). However, two measures of storm intensity - rainfall intensity and slope of the rising limb of the hydrograph - had ranges of 285% and 367%, respectively, between the three storms and varied directly with sediment losses. Furthermore, the June 15 storm was preceded by storms on June 9 and June 11 and drying potential, as measured by mean maximum temperature and antecedent precipitation, was low. In contrast, the storm on July 22 was preceded by 23 rainless days and hot dry conditions which are conducive to soil cracking and appear to increase soil detachment upon wetting. Additional studies are planned to better define these relationships.

Concentrations of total suspended sediment at the two sampling stations on Bread Creek did not show a negative impact of road water on stream quality. In fact sediment concentrations often decreased between the upstream and downstream stations suggesting that dilution occurred along the stretch probably from small streams draining the watershed proper. Another explanation, however, is that some of the suspended sediment load may have been deposited in the stream channel between the two points. Additional work to investigate the fate and nature of sediments entering the stream are planned in an extension of this study.

CONCLUSIONS

The study demonstrated that even well established forest roads may discharge substantial quantities of sediment, but rates of erosion and the disposition of sediment depend strongly on specific site factors. Slope gradient alone accounted for most of the variation in sediment losses among road segments. Location of the cross drain culverts with respect to local drainage features determines whether ditch water and suspended sediments are shunted directly into a stream or whether they are retained by the forest floor. A large percentage of sediments eroded from the road surfaces was deposited within a short distance of the culvert outlets because of the sharp drop in flow velocities. Study results indicate a need to minimize slope gradient of the road surface where possible. If steep grades (> 6%) are unavoidable, cross drains should be spaced closely enough to minimize ditch water accumulation and placed so as to insure dispersion of road water onto relatively uniform, well vegetated side slopes. Predicted rates of soil erosion per mile of roadway surface using the Universal Soil Loss Equation were 1200% higher than the measured rates. These results cast serious doubt on the method used for predicting erosion on forest roads in the Arkansas assessment.

ACKNOWLEDGMENTS

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SOIL LOSSES FROM A "MINIMUM-STANDARD" TRUCK ROAD CONSTRUCTED IN THE APPALACHIANS

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ABSTRACT

Soil losses from 11 road sections in the central Appalachians were measured. Nine of the sections were located on a newly constructed "minimum-standard" truck road and two were on a graveled higher standard road. Average annual soil losses on the "minimum-standard" truck road ranged from 44 tons/acre for ungraveled road sections to 5 tons/acre for sections surfaced with 3-inch clean limestone gravel. Soil losses on the graveled sections of the "minimum-standard" road were similar to those measured on the higher standard road.

Introduction

Land managers have long recognized that forest roads are necessary for most types of forest management activities. They also know that roads are costly to build and cause many water quality problems on forest land (Packer 1967). Excessive road costs have become a major concern of foresters, especially in the rugged Appalachians where road costs are often high and timber that is logged often is low in volume and value. As an alternative to more costly, carefully engineered forest roads, Kochenderfer and Wendel (1980) proposed a "minimum-standard" truck road which they believe will provide the necessary utility, protect other resources, and cost much less than higher standard roads. Such a road was constructed in 1979 and instrumented to measure soil loss.

The Minimum-Standard Road

A section of a "minimum-standard" road is illustrated in Figure 1. These roads are suitable for the large three-axle trucks used to haul logs in Appalachia and for vehicles with clearances equivalent to those of pickup trucks. We feel that the minimum-standard truck road offers land managers a good option when roads are constructed primarily for timber management activities, fire control, or hunter access. In order to keep road construction costs within acceptable limits, the following procedures were used to construct the "minimum-standard" roads:

- Roads were constructed from a flagged centerline. There was no formal road design or construction staking.
- Nothing smaller than a D-6 bulldozer or its equivalent was used to any extent.

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Figure 1.--A newly constructed minimum-standard truck road on the Fernow Experimental Forest.

- Each road job was advertised for competitive bids. The hourly bid rate included the bulldozer and an operator who was experienced in forest road construction. A competent supervisor-helper stayed with the machine operator most of the time.
- All right-of-way clearing was done with the bulldozer in conjunction with road building. Standing trees were pushed or pulled over and removed from the roadbed.
- Cut banks were usually left vertical except when bank height exceeded 5 feet or a ditch line was involved. Then banks were rough sloped or benched. When banks were left vertical, 2 to 3 feet of extra road width was allowed for bank sloughing.
- Culverts were used only at streams and seeps which were live at least 6 months a year. Ditches were constructed as needed to collect water for culverts.
- Broad-based dips spaced at about 200 foot intervals were used to control other water (USDA Forest Service 1940; Hewlett and Douglass 1968).
- Seeding was done with a cyclone seeder because most exposed soil suitable for seeding was on the roadbed.

Detailed cost data for eight "minimum-standard" roads that were constructed in the central Appalachians between 1977 and 1983 were presented by Kochenderfer et al. (1984). The average cost per mile excluding gravel ranged from $5,048 to $14,424, averaging $8,119.

Methods of Measuring Sediment Production

Nine study sections, each defined as the drainage area between two broad-based dips, were established on a newly constructed "minimum-standard" truck road (Stonelick road). Each section was instrumented to measure soil losses and to provide a collection point for water quality samples. Two study sections were also established on a higher standard road (Fernow Loop). This road is completely ditched, with metal culverts spaced about 300 feet apart. The sloped banks have become well stabilized with vegetation since the road was constructed in the 1930's. Drainage areas on these two sections were isolated by using open-top culverts to direct water into existing culverts. Measurements were made at the culvert outlets. All the study sections are described in Table 1. Both roads were constructed in Calvin channery loam soil.

Three treatments were randomly replicated three times each on the Stonelick road. Treatments included surfacing with (1) 3-inch clean gravel, (2) 3-inch crusher-run gravel, and (3) no surfacing (Fig. 2). Another treatment (1-inch crusher-run gravel) was replicated twice on the Fernow Loop road. Figure 3 illustrates the method used for measuring sediment production from a road section. Water draining from the road area was first directed into a sediment box, where some of the heavier material settled out. Suspended sediment and water were directed onto a Coshocton wheel, which sampled .5 percent of the outflow from the box and diverted it into a 225 liter storage tank. Tanks were usually emptied when they were half full. Volumes were recorded and the contents agitated while two 250-ml samples for sediment analysis were collected from a spigot on the bottom of the tank.

Figure 3.--One of the installations being used to measure sediment production on the Stonelick road.

Table 1.--Drainage areas of study sections

Replication number	Treatment[a]	Length	Width	Area	Cut bank height	Road grade
		-------feet------		acres	feet	percent
		STONELICK ROAD				
	A	155.1	18.9	.067	4.8	10
1	C	223.1	17.0	.087	4.8	12
	B	180.6	16.8	.070	4.0	10
	A	200.5	17.3	.080	5.0	6
2	B	196.4	18.2	.082	6.1	5
	C	209.0	16.2	.078	5.1	8
	C	143.0	18.5	.061	4.7	7
3	A	123.4	17.2	.049	4.5	10
	B	112.7	19.8	.051	5.4	8
		FERNOW LOOP ROAD				
	D	322.7	15.3	.114	4.5	3
	D	278.4	15.0	.096	5.0	3

[a] A = 3-inch clean gravel
B = Ungraveled
C = 3-inch crusher-run gravel
D = 1-inch crusher-run gravel

In the laboratory, the sediment samples were filtered to determine their content if the water was relatively clear. The sediment concentration of runoff from bare road sections sometimes reached 20,000 mg/l. These "dirty" samples were poured into aluminum pans and the water evaporated in an oven at 105° C. Sediment concentration was determined as the net weight of the residue in the pan.

Periodically, the material in the sediment box was measured to determine its cubic-foot volume and subsamples were collected and ovendried to determine its bulk density. Sediment volume multiplied by average bulk density gave sediment weight collected in the box. This value was added to the suspended sediment to yield total oven-dry sediment produced from each treatment section during specified time periods.

Results and Discussion

Soil losses during the first and second years after road construction are presented for each of the 11 road sections (Table 2). A one-way analysis of variance run on soil losses each year for the 11 instrumented road sections indicated a difference significant at the .05 level among treatments for both years. A Student/Newman/Keul's multiple range test performed on the first year's data (Steel and Torrie 1960) showed that soil loss from ungraveled road sections was significantly larger than that from the other sections. Soil losses from the unsurfaced sections ranged from 14.6 to 61.7 tons/acre; losses from the sections surfaced with 3-inch crusher-run stone ranged from 2.5 to 12.1 tons/acre.

It may be instructive to examine these extreme values and attempt to determine their causes. The large soil loss (12.1 tons/acre) from the section covered with 3-inch crusher-run gravel was caused by a bank that slumped into the dip. This material was not removed but permitted to stabilize naturally. Hence, much of the slumped material was eroded by surface water and measured as soil loss from this section. The unusually low soil loss (14.6 tons/acre) from the ungraveled section in Replication 3 can be explained by the high coarse fragment content of this section (Fig. 4). These large variations in soil losses are probably typical of most roads in the central Appalachians. As we learn to recognize which road sections are apt to erode most severely, we can apply gravel only to those sections instead of graveling the entire road.

Soil losses increased on all the road sections the second year (Table 2). Student/Newman/Keul's multiple range test indicated that the differences between the graveled sections and bare sections were significant at the 5 percent level. Differences between the graveled sections for the same year were not significant. It should be pointed out that the Stonelick road was gated the first year and only light traffic required for maintenance of the research installations was permitted. Traffic was not controlled on this road the second year. In addition to numerous pickup trucks, 1,161 tons of gravel (50 truckloads) were hauled over all the replications during the second year. The Fernow Loop road was open to continuous year-round traffic both years. Gravel on the Stonelick road has become more embedded on all the sections, thus exposing more soil.

Table 2.--First- and second-year sediment yields in tons/acre from the four treatments on the Stonelick and Fernow Loop roads

Treatment	Replication	Year	
		First	Second
		------tons/acre-------	
3-inch clean gravel	1	5.2	6.3
	2	4.9	10.5
	3	2.4	3.1
Mean	-	4.2	6.6
Ungraveled	1	61.7	62.6
	2	39.4	62.2
	3	14.6	25.8
Mean	-	38.6*	50.2*
3-inch crusher-run gravel	1	4.7	12.7
	2	12.1	28.5
	3	2.5	7.6
Mean	-	6.4	16.3
1-inch crusher-run gravel	1	3.7	4.4
	2	3.9	9.9
Mean	-	3.8	7.2

* Significantly different at the .05 level.

Figure 4.--The ungraveled section in Replication 3 showing the high coarse fragment content.

When the 2 years were averaged, there was a significant difference ($P<0.05$) in soil losses among the treatments (Table 2). Average soil losses were 44.4 tons/acre for the ungraveled sections; 11.4 tons/acre for the sections surfaced with 3-inch crusher-run stone; 5.5 for the two sections on the Fernow Loop road which were surfaced with 1-inch crusher-run gravel; and 5.4 tons/acre for the sections surfaced with 3-inch clean stone. Thus, the ungraveled sections lost 8 times more soil than the sections surfaced with 3-inch clean stone. Part of the material lost from the 3-inch crusher-run sections was limestone dust from the gravel.

In general, the largest increase occurred the second year in Replication 2 which has a low natural coarse fragment content. Based on experience with other roads, Replication 2 is located in a portion of the road more susceptible to rutting than the other replications. This section also has seeps which are active after major storms, especially during the dormant season. The large loss from the section surfaced with crusher-run gravel can probably still be attributed to the slump that occurred the first year. Another problem is that the bare section is located between the other two sections in the replication and some "tracking" of mud onto these two graveled sections from the bare section is occurring. The large soil loss the second year from one of the sections graveled with 1-inch crusher-run gravel can probably be attributed to logging traffic. About 150 mbf of logs were hauled over these sections between February and April 1982. Because roadbeds were thawing during this period, severe rutting occurred on one of these sections.

The roads instrumented for this study were constructed on a Calvin channery loam which is rated as having a moderate bearing capacity when wet (Losche and Beverage 1967). Some rutting is visible on the ungraveled sections of Replications 1 and 2 but it is not severe. Subjecting unsurfaced roads to uncontrolled traffic in this area, where it usually does not freeze or remain dry for extended periods, will normally result in some rutting. Rutting would probably have been more severe on some of our soils that have a higher clay and lower coarse fragment content. Soil losses would also be expected to be higher on such soils. Traffic has averaged about 30 vehicles a week on the Stonelick road, primarily light trucks during periods when rutting would be expected. If this road had been subjected to uncontrolled heavy traffic during the period January to April, severe rutting would probably have occurred on the ungraveled road sections. It should be emphasized that the soil losses reported here do not necessarily represent sediment contributions to streams. Whether this eroded soil reaches a stream depends on many factors, such as road location, volume of water available for sediment transport, effectiveness of sediment traps, slope steepness, etc.

Conclusions

Soil losses were much larger from ungraveled road sections than from graveled ones on two roads in the central Appalachians. Average annual soil losses on a "minimum-standard" truck road were 44.4 tons/acre from ungraveled sections; 11.4 tons/acre from sections surfaced with 3-inch crusher-run limestone gravel; and 5.4 tons/acre for the sections surfaced with 3-inch clean limestone gravel. Losses on a higher standard road graveled with 1-inch crusher-run limestone gravel averaged 5.5 tons/acre. The ungraveled sections lost 8 times more soil than the sections surfaced with 3-inch clean limestone gravel.

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FIGURE LEGENDS

Figure 1.--A newly constructed minimum-standard truck road on the Fernow Experimental Forest.

Figure 2.--Looking down the section in Replication 1 graveled with 3-inch crusher-run gravel.

Figure 3.--One of the installations being used to measure sediment production on the Stonelick road.

Figure 4.--The ungraveled section in Replication 3 showing the high coarse fragment content.

FUNCTIONAL REQUIREMENTS AND DESIGN PARAMETERS OF SWING-TO-BUNCH FELLER-BUNCHERS FOR FOREST THINNING

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Text of this paper begins on page 363.

FIELD STUDIES AND ANALYSIS OF A FELLER-BUNCHER OPERATION

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ABSTRACT

This paper describes field studies and the subsequent analysis of production data of a Feller-Buncher unit. The studies were conducted in conjunction with the harvesting of two different hardwood stands. Time standards and cost estimates are presented.

INTRODUCTION

The benefits to be derived from the use of a feller buncher are relatively easy to imagine. However, unless one has had field experience with one of these units it would be difficult to quantify the benefits for any practical use. Indeed, field experience which has not been documented is little better than no experience at all in terms of others being able to apply this knowledge. The apparent absence of documentation on the use of a Feller-Buncher, particularly in eastern hardwood stands, was what led to the study reported herein. Our purpose in this paper is to present the production and operating characteristics of a specific feller buncher.

The unit studied was a National Hydro-Ax Series 511 Prime Mover with a Morbark 20 inch Feller-Buncher attachment.[3] The machine was four years old at the time of the study. The Feller-Buncher operator had four years experience running the machine and had a total of 17 years worth of logging employment.

SITE LOCATION

A preliminary investigation was conducted in late August of 1982. This investigation sampled elemental and production cycle times from a harvesting operation in Dundus, Ohio. The harvesting site was several hundred acres in area and sampling took place when the site was approximately half cut. A clear-cut harvesting method was being used for sale of pulpwood.

The preliminary investigation served as an introduction to Feller-Buncher operations. In reviewing the preliminary investigation, it was decided that an accurate report of Feller-Buncher mechanization would require observing the machine clearcut an entire harvesting area, and site characteristics would have to be fully documented prior to harvest. However, the preliminary field study provided good insight into the variables to monitor and the means by

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which to accurately record them.

The final investigation was conducted in June, 1983 in Jackson, Ohio. The site consisted of approximately six acres which was also being clearcut for pulpwood. Unless otherwise noted, all production data presented in this paper was taken from this site.

Prior to harvesting, silviculture data was collected to completely specify the stand characteristics of the harvesting area. Figure 1 illustrates the shape and size of the harvesting plot. The cross hatched area had been cleared much earlier as the right-of-way for a power line.

SITE CHARACTERISTICS

Pre-harvesting data was collected through sampling one-tenth acre circular plots. This sampling was used to identify species composition, diameter at breast height (DBH), tree height, and butt diameter.

Figure 2 illustrates the relative species composition of the site. A correct interpretation of Figure 2 would reveal 47% of the trees per acre being Hickory, 20% Sassafras, 19% Oak, and the sum of the remaining species (Locust, Elm, Cherry, Maple, Poplar, Gum, Dogwood) accounting for the other 14%. Figure 3 illustrates the distribution of tree diameter at breast height.

The data contained in Figure 3 revealed an average DBH of eight inches, ranging from 4.5 inches to greater than 16 inches. The average tree height was 57 feet, with a low of 21 feet and a high of 80 feet. Stand density approximated 220 trees per acre.

GENERAL HARVESTING METHOD

The harvesting operation consisted of one Feller-Buncher, four cable skidders, one grapple, one bulldozer, one chipper, and a chain saw.

The Feller-Buncher operator would be the first to arrive on site and would begin cutting immediately. Approximately one week later the rest of the crew would arrive. The cable skidders would begin transporting felled timber to within forty yards of the chipper. The grapple transferred timber from the skidder piles to within reach of the chipper arm. Trees would then be chipped directly into vans for delivery to pulp mills.

The Feller-Buncher operator tried to maintain a one-week lead over the skidders in anticipation of possible Feller-Buncher breakdowns, as the Feller-Buncher was viewed to be the least reliable machine on the site. The cable skidders dropped timber forty yards from the chipper to stay clear of its congestion. This was desired so that skidder operations would not have to be delayed in dropping skidder loads. Such waiting becomes necessary when the skidders are transporting trees to the chipper faster than they can be chipped. This creates a stockpile in front of the chipper, whose size is limited by the length of the chipper feed arm. Once such a limit is attained, the skidders are forced to wait for trees previously piled to be chipped.

Such a process greatly inhibits the efficiency of the skidding operation.

The solution was to skid trees to piles approximately forty yards from the chipper. These bunches could accumulate in size without limit while the grapple would transfer timber from these bunches to the chipper. This allowed for uninterrupted skidding of felled trees; thereby, maximizing skidder efficiency. When inquiring as to whether this method of harvesting was the typical practice of the operator, it was learned that while not being the desired method in all cases, it was not atypical either.

PRODUCTION AND OPERATING CHARACTERISTICS

Production data was gathered by observing the Feller-Buncher in operation and recording the elemental and production cycle times through the use of a stop watch. The time study elements which made up one full cycle of the Feller-Buncher were defined as follows: an "unloaded move" begins following the dropping of felled trees and ends when the machine is in position for a cut; a "cut" follows every unloaded move and terminates when the machine begins travel; a "loaded move" follows cuts and ends when the machine is positioned for the next cut; a "drop" follows the last cut of a given cycle and terminates when the machine has successfully bunched accumulated trees.

Using the foregoing terminology, cycles are defined as the amount of time transpiring between successive "drops". Cycles were easily distinguished as the vehicle was forced to travel in a reverse direction following every "drop". This occurs because the trees are dropped from the front of the machine. Thus, consecutive cycles were delineated by the start of a reverse movement.

Time Study Results

The elemental time study results are summarized in Table 1. One hundred and eighty five cycles were accumulated in generating Table 1. The number of cycles is obtained by observing the number of drops, as a cycle is defined as time between successive drops.

The delay element appearing in Table 1 was introduced to represent all impedances to the completion of a cycle. Such an element was necessary as cycles were not completely specified by the move, cut, and drop elements. The delays observed included personal, determination of cutting patterns, removing debris from the machine, mechanical breakdowns, and boundary checks. It is believed that due to an insufficient number of observations, standards concerning delays will not be accurate.

A review of Table 1 reveals that the number of observations differs for every element. This is a result of the machine's capacity to accumulate several trees per cycle. The number of trees cut in a given cycle will specify the number of loaded moves and cuts, while every cycle has one unloaded move and one drop. Thus, three trees sheared in a given cycle will require three cuts, two loaded moves, one unloaded move and one drop. Furthermore, unloaded moves occurred more frequently than drops, because some unloaded moves were simply transportation to new cutting areas, not the beginning

of the cycle.

A clearer picture of the variation in the elemental time study data is presented in Figures 4, 5, 6, and 7. These figures illustrate the relative likelihood of observing an element falling within a specified range of values.

Time study data was also collected for complete cycles. Recall that a cycle time represents the time between successive drops. One advantage Feller-Bunchers offer is in the felling of several trees per cycle. The number of trees cut in a given cycle ranged from one to six, averaging 1.57. The restriction on the maximum number of trees cut in a cycle is tree size (i.e., butt diameter, DBH, tree height).

The capacity of a Feller-Buncher, as it relates to tree accumulation, is usually defined by the machines inability to accommodate additional trees. When harvesting on hilly terrain capacity might alternatively be defined as the point when the accumulation of additional trees causes a risk of the machine tipping. Tipping was not observed during this investigation, nor was it commonly experienced by the operator. Nevertheless, tipping does represent a limitation to the accumulation of trees when harvesting on hilly terrain.

Table 2 summarizes the data for cycle times and the number of trees cut per cycle. This summary was obtained by taking the cycle time data from Table 1 and adding to it additional observations made on cycles only. Table 3 presents another view of cycle time data with respect to the number of trees cut per cycle.

The two tables of cycle time data complement each other. Although the average cycle required 0.79 minutes and sheared 1.57 trees, this summary poses significant difficulties in actual application as it is impossible to shear 1.57 trees. One either cuts one tree or two, but never a value in between. This is a result of the discrete nature of tree cutting. The presentation of Table 3 was provided to partially alleviate this problem.

Observations On Trees Cut Per Cycle

Trees cut per cycle represents perhaps the most important measure of machine utilization. One of the major contributions of Feller-Buncher mechanization rests in its ability to fell several trees before bunching. Maximum machine utilization would result when the average number of trees cut per cycle approaches the machine limit.

Although an average of 1.57 trees cut per minute is rather small, it is not without explanation. The boundary lines were very close to adjacent property which could not sustain the damage of falling trees or limbs. Thus, special care in felling and bunching boundary area timber was required. Such care usually resulted in the shearing of only one tree per boundary area cycle. This policy reduces the likelihood of accidentally losing the accumulators grip of felled timber.

It is believed that the effects of boundary areas were further aggravated due to the size of the harvesting area (six acres). Such a small area

qualifies a good proportion of the total trees harvested for "Boundary Conditional Felling and Bunching." It is believed that boundary conditions accompanied with the small harvesting area biased the results of this investigation regarding the trees cut per cycle, and, as a result, the cycle time.

In an attempt to ascertain the degree to which the previously mentioned factors affected the time study, a comparison of the 1982 and 1983 production data was undertaken.

Sampling in 1982 took place in the middle of a 200 acre clearcut; thus, boundary conditions were not present. A comparison of the production data indicated that the average number of trees felled per cycle was significantly less in 1983 as compared to 1982 (see Table 4). Two possible explanations for this discrepency arise: the trees of the harvesting site were much larger in 1983 or the boundary conditions of 1983 had a significant impact.

Analysis of tree sizes for the data was possible through DBH measurements, and revealed that DBH's of 1982 and 1983 did not differ significantly. This leaves one alternative of the two previously mentioned: boundary conditions. Since the effect of boundary conditions was not anticipated, data collection did not permit any statistical tests being run that could conclude the statistical significance of boundary conditions. However, through the process of elimination boundary areas represent the strongest remaining cause of the average number of trees felled per cycle of 1983 smaller than 1982. Recall, in boundary area felling and bunching it was a policy of the operator to shear only one tree per cycle.

Production Summary

A total of 1059 trees were felled on the site studied in 1983. This yielded approximately 780 tons of timber (based on Mill receipts), and required 543 productive minutes and 675 cycles of the Feller-Buncher. A hubometer was mounted on the Feller-Buncher's right front wheel. This device monitored the number of revolutions the tire accumulated during harvesting. By measuring the circumference of the tire, the total distance traveled was determined to be approximately 13 miles.

Manipulation of the above information yields: 23 pounds harvested for every foot of Feller-Buncher travel, and 86 tons harvested per productive hour.

Economic Analysis

The economic evaluation of the total hourly operating cost for the Feller-Buncher is provided in Table 5. Various estimates used in this evaluation were obtained from the operator. Hourly operating costs were estimated to be $35.15 per productive hour and appeared consistent with the owners records.

The combination of hourly operating costs and other production data allows for the derivation of the following statistics: $315 to harvest 780 tons of timber, $66.00 per acre, and $0.40 per ton harvested.

Three points need to be raised concerning the above figures and those in Table 5. The first concerns the operator supplied machine utilization level of 75 percent. This implies that one complete day of downtime will be experienced for every four days of production. The major cause for such a large proportion of downtime is in the acquisition of replacemente parts. Other than the parts that frequently failed, the majority of replacements had to be flown in directly from the manufacturer. Typically, an employee of the logging company then drove to the nearby airport to receive the part. This process took anywhere from several days to more than a week. Had the delays in part acquisition been reduced or eliminated the utilization level should have risen substantially.

A second point to consider is the oil and lubrication figure of $3.20 per productive hour. This high cost is a result of losing approximately forty gallons of hydraulic fluid every time an hydraulic hose breaks. These hoses leading to the shear head brake frequently as they are in direct contact with falling limbs and branches. The manufacturer has recently indicated that the frequency of hydraulic lines breaking has been reduced via the use of protective coverings. Such protection is expected to reduce the hydraulic fluid requirements and consequently reduce the hourly oil and lubrication cost.

The third point is that all cost figures apply strictly to the use of the Feller-Buncher. Chain saw felling, which was also used, is not considered in this paper, nor was it studied.

USE OF THE RESULTS

The most valuable contribution to be derived from a study of this nature is if guidance can be given as to some simple ways of extrapolating the results to future harvesting areas. With estimates of the total trees to be harvested, crude estimates of total harvesting time can in fact be derived from Table 2 and Table 4, depending on whether the area to be harvested will be restricted by boundary conditions or not. For an extremely large area, the trees to be harvested could be divided into those which would be restricted by boundary conditions and those which would not. Regardless of which Table is used, a conditional assumption would have to be made; that the stand density would have little or no effect on the result. Keep in mind, however, that this study did not generate data which would allow one to either accept or reject this assumption.

Another approach to the use of the data is to develop models of harvesting time using regressive methods. It was felt that models could be developed which would allow for a more accurate prediction of total harvesting time than would be possible by simply using the averages contained in Tables 2 and 3. However, subsequent modeling proved to be of limited value. The very best model was of the following form:

$$\text{Cycle time} = .3658 + .2765 \times (\text{no. of trees cut per cycle})$$

Although the intercept and coefficient are statistically significant ($\alpha = .05$), only 23 percent ($R = .47$) of the variation in the observed cycle times could be explained by the model.

If the accumulated DBH and/or tree heights had been available for each cycle observation, it may have been possible to improve the predictability of the foregoing model by adding these independent variables. However, safety considerations, due to the speed at which the Feller-Buncher operated, meant that it was not possible to collect data which would allow one to accurately correlate the measurements of felled trees with specific cycles.

A third method of using the available data to predict total harvesting time is through computer simulation. The simulation logic rests on the operator's ability to look at a stand and estimate the "average" number of trees to be cut per cycle. Once the number of trees in a given cycle is specified, the cycle is completely defined in terms of its elemental activities. In other words, the number of cuts and loaded moves can be precisely determined. Every cycle will begin with an unloaded move and end with a drop. With this in mind, a Monte Carlo simulation was developed which had the capacity to generate total harvesting time for any specified combination of total trees in the stand and expected average trees cut per cycle. Both values were required as input to the model.

The simulator would generate cycles until all trees were cut. The number of trees cut in any one cycle was randomly generated from a process generator of a normal distribution, the mean of which was input by the user. The generated values were truncated to an integer number of trees, and curtailment occurred at one (1), for values less than one (1), and at six (6), for values greater than six (6). These curtailment limits represent the actual limits derived from the production data of the 1983 field study.

For a given cycle, elemental times were extracted from the actual distributions specified in Figures 4, 5, 6, and 7. Thus, a Monte Carlo selection process was used for the elemental times. In summary, the model would generate the number of trees cut, the corresponding elemental times (i.e., unloaded move time, cutting time (s), loaded move time (s), and drop time), and then sum the elemental times to obtain a cycle time. Total harvesting time was obtained by accumulating successive cycle times.

A set of results from the simulator is displayed in Figure 8. This figure could be used by an operator to estimate total harvesting time for a particular stand. For example, suppose a 10 acre stand contained approximately 200 trees per acre and the expected number of trees cut per cycle was three. One would enter the graph in Figure 8 with a total of 2000 trees and a value of three trees cut per cycle, and through interpolation estimate the total harvesting time from the y axis (e.g., 750 minutes). It must be noted that all harvesting times extracted from Figure 8 are expressed in productive minutes, meaning that allowances for delays are not included.

When the hourly operating costs are incorporated with the simulation results contained in Figure 8, an estimate of production costs due to felling may be estimated.

Two points should be raised concerning the validation of the simulation results. The first is that the elemental time standards are unlikely to vary much from stand to stand. In fact, a comparison of the data collected in

1982 and 1983 demonstrated little difference between the resulting elemental averages. The second point is that when the results of the simulator were compared to the actual observed harvesting time for the stand studied in 1983, there was only an 8.1 percent error in the estimate (498 minutes estimated versus 543 minutes observed). One consideration in this regard is that the inherent randomness of Feller-Buncher operation is probably more pronounced in small harvesting areas. If this assumption is true, simulation estimates for larger stands would likely be more accurate than the 8.1 percent just quoted.

CONCLUSIONS

Extrapolation of the results contained in this paper to other stands can be made. However, one must keep in mind that there is always some risk involved, since the data being used reflects specific site conditions. Clearly, additional field studies would be extremely useful in terms of understanding just how much production variation is possible and the causes of such variation.

Regarding possible future studies, a more universal form of data collection should be considered by which bunching time requirements could be collected. This was not possible in the 1983 study since the operator bunched in a "windrow" fashion. This bunching method was desired by the operator in this instance since it aided skidder efficiency, as choker attachment became difficult for "stacked timber." Thus, the bunching method was influenced by the use of the cable skidders.

An analysis of the trees not sheared by the Feller-Buncher indicated that the operator was effective at determining those trees too large to shear. Furthermore, the adopted procedure of not wasting time trying to shear small trees that were nestled between larger ones that exceded shear capacity appears to be a good one, and should be considered by other operators. Both these observations indicate that a certain number of trees will always remain for chain saw felling.

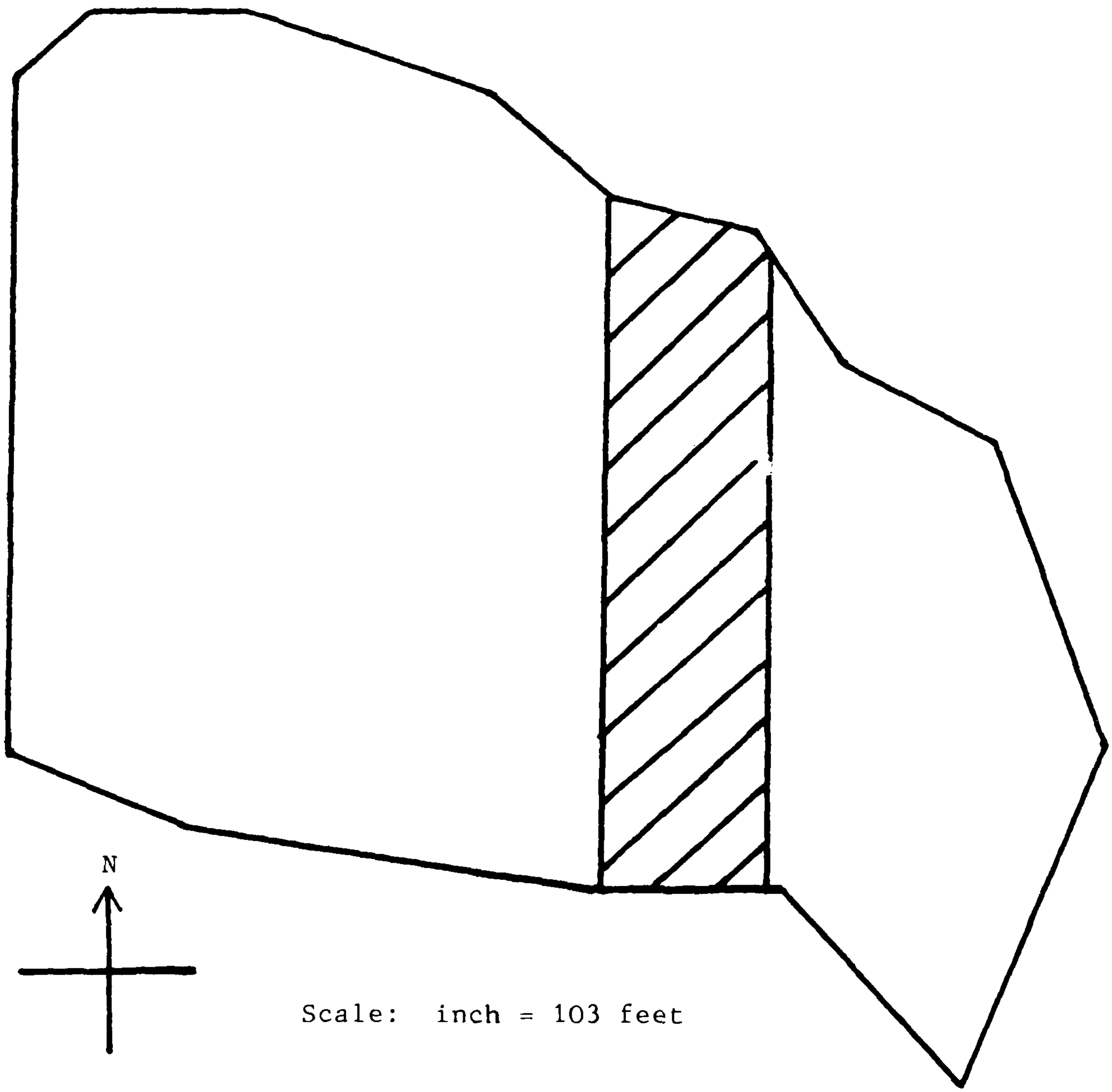
Lastly, it should be mentioned that the operator who participated in this study had been experiencing complete failure of the shear head. He had rectified this prior to the study by welding an extra plate. However, this experience indicates that more research appears to be needed concerning the structural design of the shear for hardwood felling and bunching.

ACKNOWLEDGEMENT

This paper was developed from a research report entitled, "Evaluation of a Feller-Buncher Operation in Appalachia." The report was prepared for the U.S.D.A. Forest Service, Northeastern Forest Experiment Station, under cooperative agreement 23-660, October, 1983.

FIGURE 1

Illustration of Actual Harvesting Area



Scale: inch = 103 feet

FIGURE 2

Species Composition

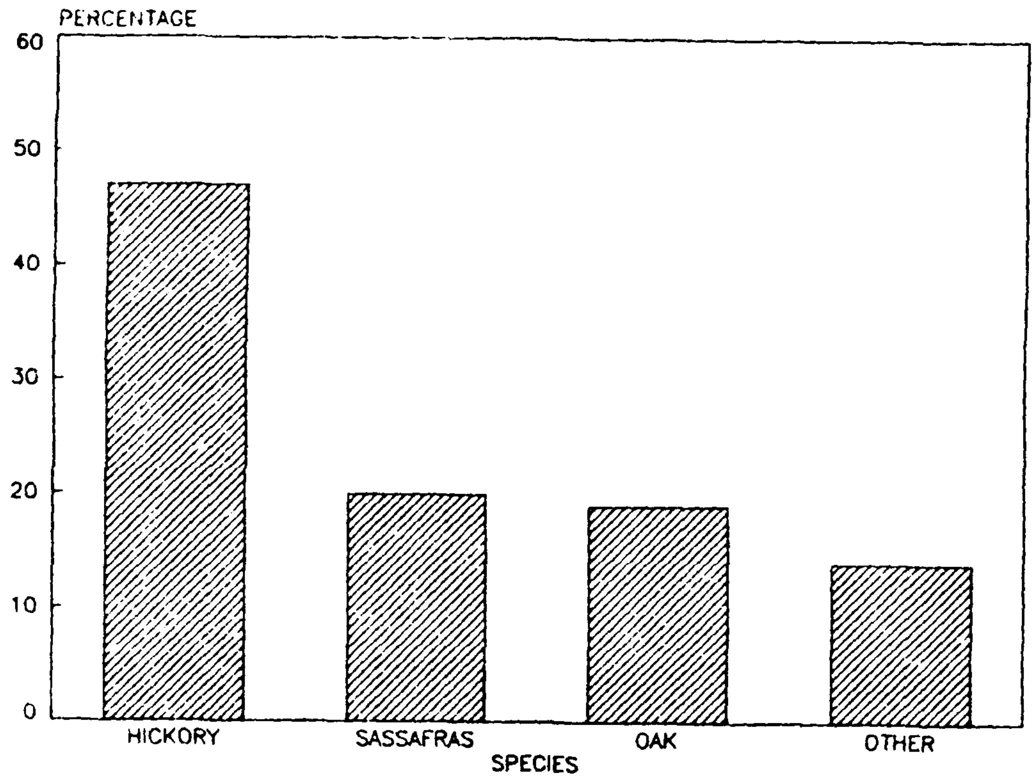


FIGURE 3

Distribution of diameter at breast height

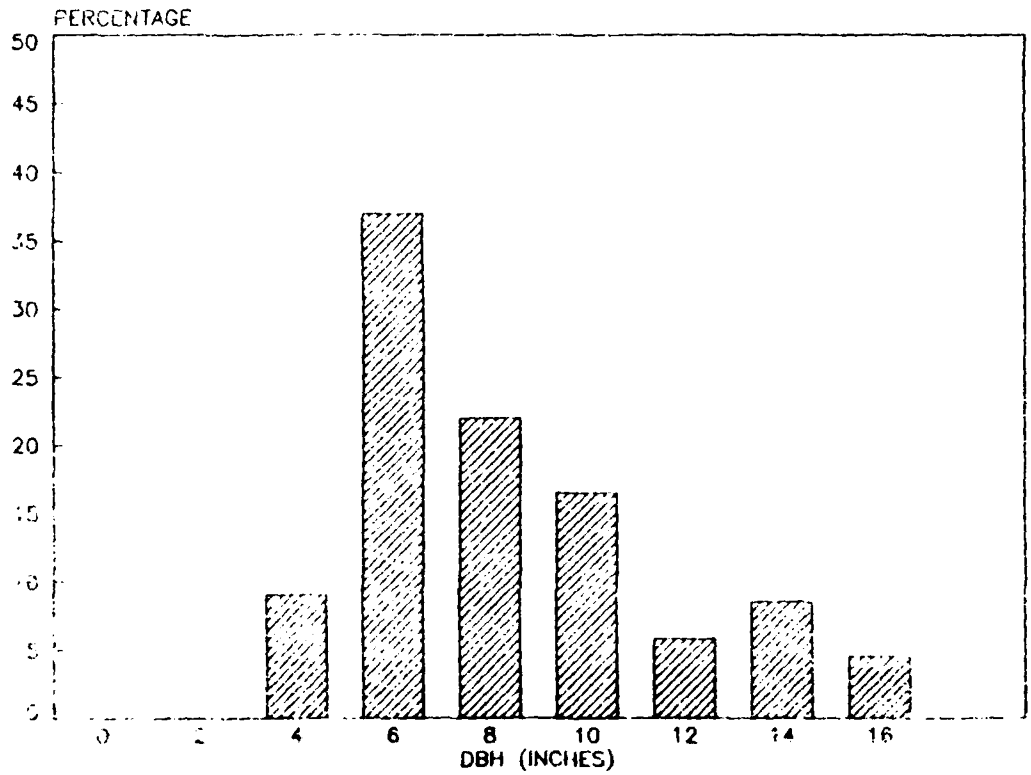


FIGURE 4

Distribution of unloaded move times

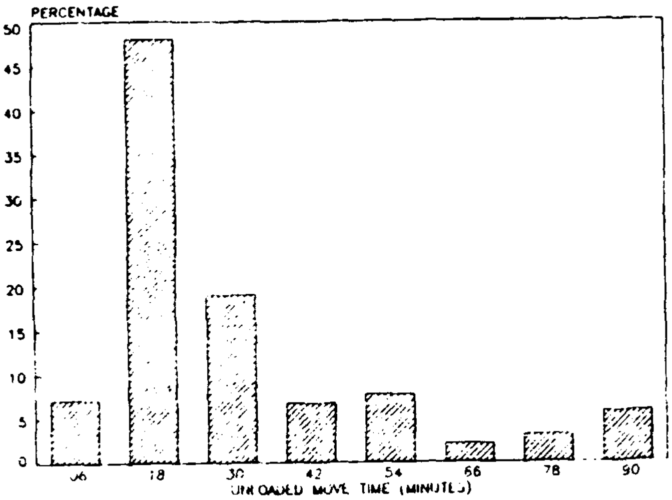


FIGURE 5

Distribution of cut times

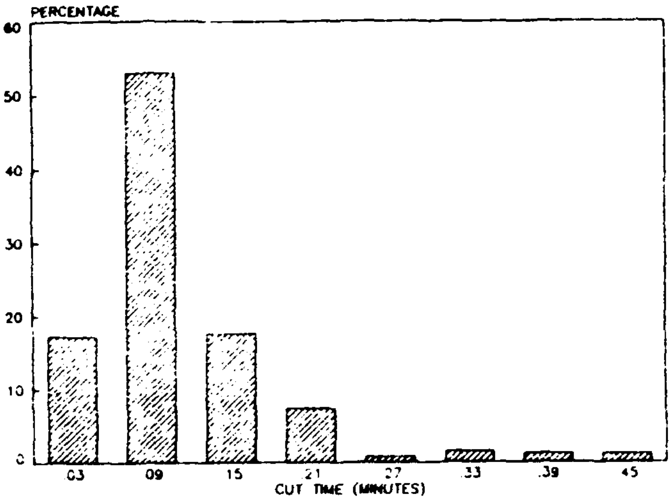


FIGURE 6

Distribution of loaded move times

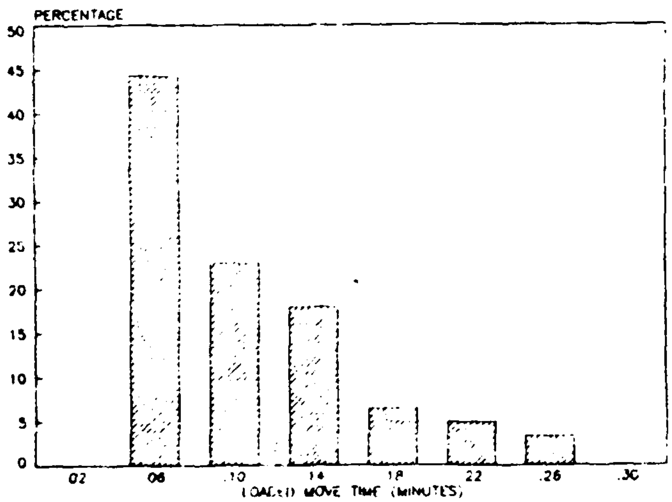


FIGURE 7

Distribution of drop times

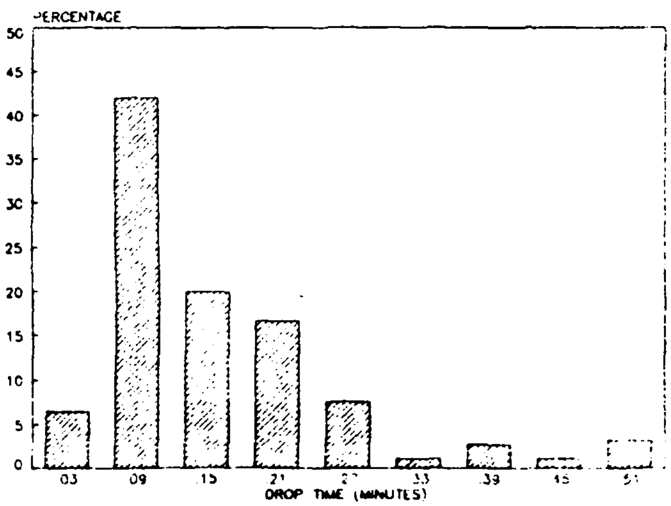


FIGURE 8

Predicted harvesting time requirements

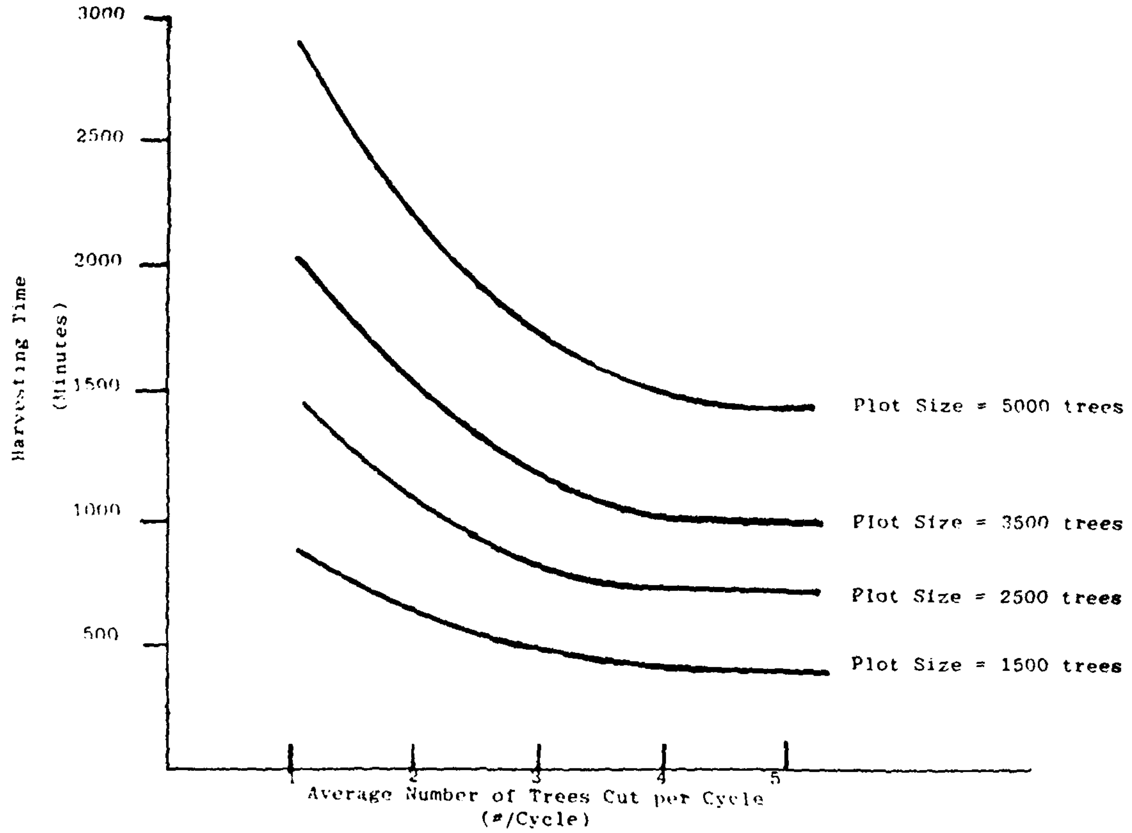


TABLE 1

Elemental time study summary

Element		# Obs.	Mean	Standard Deviation	Min.	Max.
Unloaded	Move	191	.3382	.3653	.05	3.8
	Cut	256	.1161	.0721	.01	.54
Loaded	Move	61	.1102	.0652	.05	.40
	Drop	185	.1691	.1258	.05	1.67
	Delay	17	3.906	4.1806	.45	16.0

TABLE 2

Cycle time study study

Variable	# Observations	Mean	Standard Deviation	Minimum	Maximum
Cycle Time	675	.7902	.4364	.06	2.8
Trees Cut Per Cycle	675	1.5689	.7719	1.0	6.0

TABLE 3

Conditional cycle time study summary

Trees Cut Per Cycle	Mean	Standard Deviation	Maximum	Minimum
1	.6401	.3656	.06	2.0
2	.9017	.3999	.25	2.8
3	1.1393	.4059	.55	1.96
4	1.5760	.5052	.86	2.05
5	2.0100	.5402	1.67	2.04

TABLE 4

1982 time study summaries

Variable	# Observations	Mean	Standard Deviation
Cycle Time	292	.7667	.3508
Trees Cut Per Cycle	292	1.8812	1.03214

TABLE 5

Economic analysis of feller-buncher

Description	Abbreviation	Cost	Basis
**Purchase Price	P	$70,000	
Salvage Value	S	$28,000	40% P
Estimated Life	N	5 years	
*Working Days/Year		250 days	
*Scheduled Hours	SH	2,500 hrs.	
*Utilization	U	75%	
Productive Hours	PH	1,875 hrs.	SH/U
Average Value of Investment	AVI	$53,200	$\frac{(P-S)(N+1)}{2N}$ +S
Depreciation	D	$ 8,400	(P-S)/N
Interest/Insurance/ Taxes	IIT	$12,768	(24%AVI)
Yearly Fixed Costs	YFC	$21,168	D + IIT
Hourly Fixed Costs	HFC	$11.29/hr.	YFC/PH
Maintainence/ Repair	MR	$4.48/hr.	100% D/PH
**Fuel Costs	F	$4.80/hr.	
Tires	T	$0.71/hr.	$\frac{\$1000/tire}{PH}$
*Oil/Fluids/ Lubricant	O	$ 3.20/hr.	
Hourly Operating Cost	HOC	$13.19/hr.	MR + F + O
Hourly Machine Cost	HMC	$11.29/hr.	HFC
*Labor Cost	LC	$10.67/hr.	Wage*SH/PH
Hourly Cost Total		$35.15/hr	

*Information obtained from the Feller-Buncher Operator

**Information obtained from manufacturer.

TESTING THE FMC FT-180CA HIGH-SPEED STEEL TRACK LOGGING VEHICLE

Cleveland J. Biller[1]

ABSTRACT

The FMC FT-180CA high-speed steel track logging vehicle was field tested on the George Washington National Forest near Covington, Virginia. Pulpwood and sawlogs were harvested in the clearcut operation. The average volume per turn was 102 cubic feet of Appalachian hardwoods. Skidding was uphill; maximum adverse grade was 44%. An average skid of 1190 feet took 14.9 minutes.

INTRODUCTION

The FMC FT-180CA steel track logging vehicle or tracked skidder is the newest configuration in the family of track-laying vehicles used extensively by the forest products industry. The Model FT-180CA was developed by FMC,[2/] a major manufacturer of off-road military vehicles for the last 40 years. Technology gained from developing tracked vehicles for the military and from feedback on approximately 850 FMC 200 tracked logging skidder vehicles formed the basis of the Model 180CA prototype design.

In early spring 1983, an agreement was made between FMC, George Washington National Forest, and S. A. Bennett Logging Company to conduct a production study on the prototype FMC FT-180CA. FMC Corporation supplied the machine and S. A. Bennett's logging crew operated the machine on the James River District of the George Washington National Forest. The clearcut area originally was designed for a rubber-tired skidder sale, but since the FMC FT-180CA was capable of operating on steep slopes, it was determined the FMC could harvest the area with fewer skid trails.

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2/ The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Two time studies were conducted on the logging operation. The first was by Forest Engineering Incorporated under contract to FMC. Forest Engineering Incorporated (1983) recorded the FT-180CA's production during the first 2 weeks of its operation. The second time study was done by the Forest Engineering Research Unit of the Northeastern Forest Experiment Station, Morgantown, West Virginia. The purpose of this paper is to present an analysis of the FMC FT-180CA tracked skidder.

EQUIPMENT

The basic machine configuration is shown in figure 1. The running gear consists of a forged steel track and torsion bar suspension, the latter mounted to a steel, unitized, lower chassis structure. The operator's compartment is located behind the engine, and is equipped with rollover protection (ROPS) and guards. Mounted on the rear of the chassis is a pivotable arch with integral fairlead. The primary function of the hydraulically actuated arch is to lift the ends of the logs onto the vehicle (fig. 2) to provide better load distribution on the suspension thus increasing flotation, traction, and skidding efficiency.

The vehicle is powered by a 3-53 Detroit Diesel and a Clark 3-speed transmission. Power is supplied to the tracks through an operator-controlled steering differential and final drives. Applying the steering lever slows one track while increasing the speed of the other. Power is provided continuously to both tracks during a turn.

The suspension consists of four roadwheels on each side that are mounted on roadarms. Each roadwheel and arm assembly is sprung individually using a torsion bar. The individually sprung roadwheels provide differential vertical movement to mold track to uneven terrain and obstacles thus reducing shock loads to the vehicle and operator. Each track drive sprocket is located at the front of the vehicle with dual spockets, which are reversible to prolong life. The rear idler is adjustable to provide proper track tension by adding or bleeding grease from an adjustment cylinder (Williams 1973).

LOGGING CONTRACTOR

S. A. Bennett Logging Company operated the FMC machine on a timber sale in the George Washington National Forest. Bennett Logging Company was hauling long-length pulpwood to the Westvaco mill in Covington, Virginia, and sawlogs to their mill near Clifton Forge, Virginia. The operation consisted of the following: one chain saw bucking at the landing; one hydraulic knuckleboom loader; one man operating the FT-180CA skidder; one man felling, limbing, topping, and aiding in chocker setting; and two trucks.

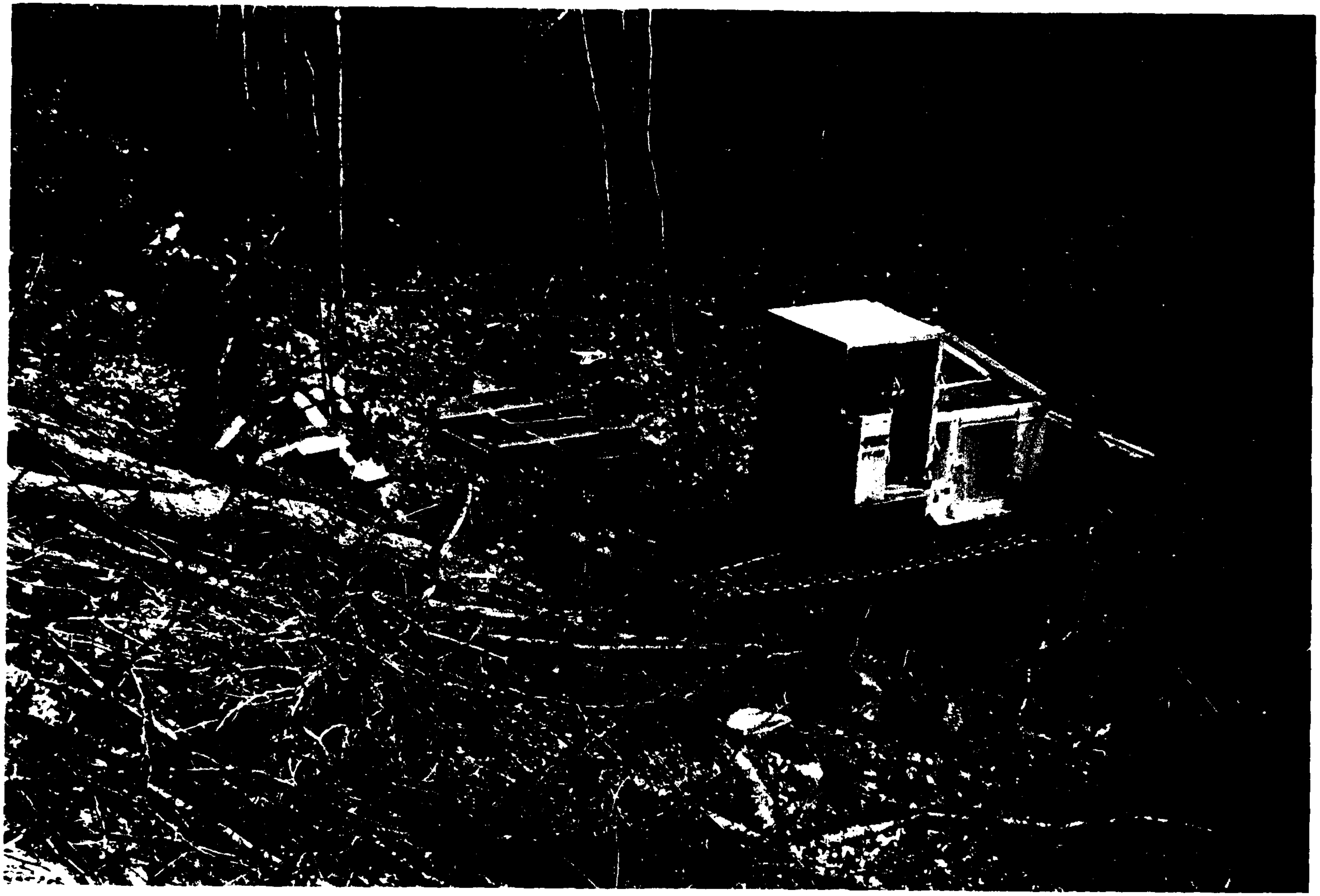

Figure 1.--FT-180CA with arch extended hooking up a load of logs.

Figure 2.--FT-180CA with a load of logs on the retracted arch traveling toward landing.

HARVEST UNIT

The area harvested was in the James River District of the George Washington National Forest. This unit orginally was designed to be harvested with rubber-tired skidder on constructed skidroads. The logging contractor and the USDA Forest Service had agreed on skidroad locations for the rubber-tired skidder. Figure 3 is a three-dimensional representation of the harvest area, showing the rubber-tired skidder's designated skidroads (using perspective plot, USDA Forest Service 1980). If a rubber-tired skidder had been used, 4,550 feet of skidroad would have been required to harvest the 27 acres, or 168 feet per acre (Forest Engineering Incorporated 1983).

Skidroads were relocated for the FT-180CA skidder; two skidroads were located along two of the major ridge lines in the unit (fig. 4). The length of the skidroads was 2,644 feet or 98 feet per acre. Figure 5 shows the profile of the left skidroad used in the study--the one used during the second time study. Slopes ranged from a 10 percent favorable grade to adverse grade of 44 percent.

TIME STUDY METHODS

The snap-back method of time study was used to obtain elemental times. Cycle elements were:

Travel Empty: Started when FMC left landing and ended when FMC operator left machine to hook chokers.

Hook Chokers: Started at end of travel empty and ended when FMC operator started to winch logs to FMC.

Winch Lateral: Started at end of hook chokers and ended when machine started toward landing.

Travel Loaded: Started at end of winch lateral and ended when FMC arrived at landing. If winching required during transport to the landing, it was recorded as a delay and excluded from travel loaded time.

Unhook Chokers: Started at end of travel loaded and ended when FMC left landing. The bucker unhooked chokers.

Element Delays: Any delay associated with an element. The following is a list of element delays.

Travel Empty Delays: None.

Hook Chokers: Position machine to line up with load.

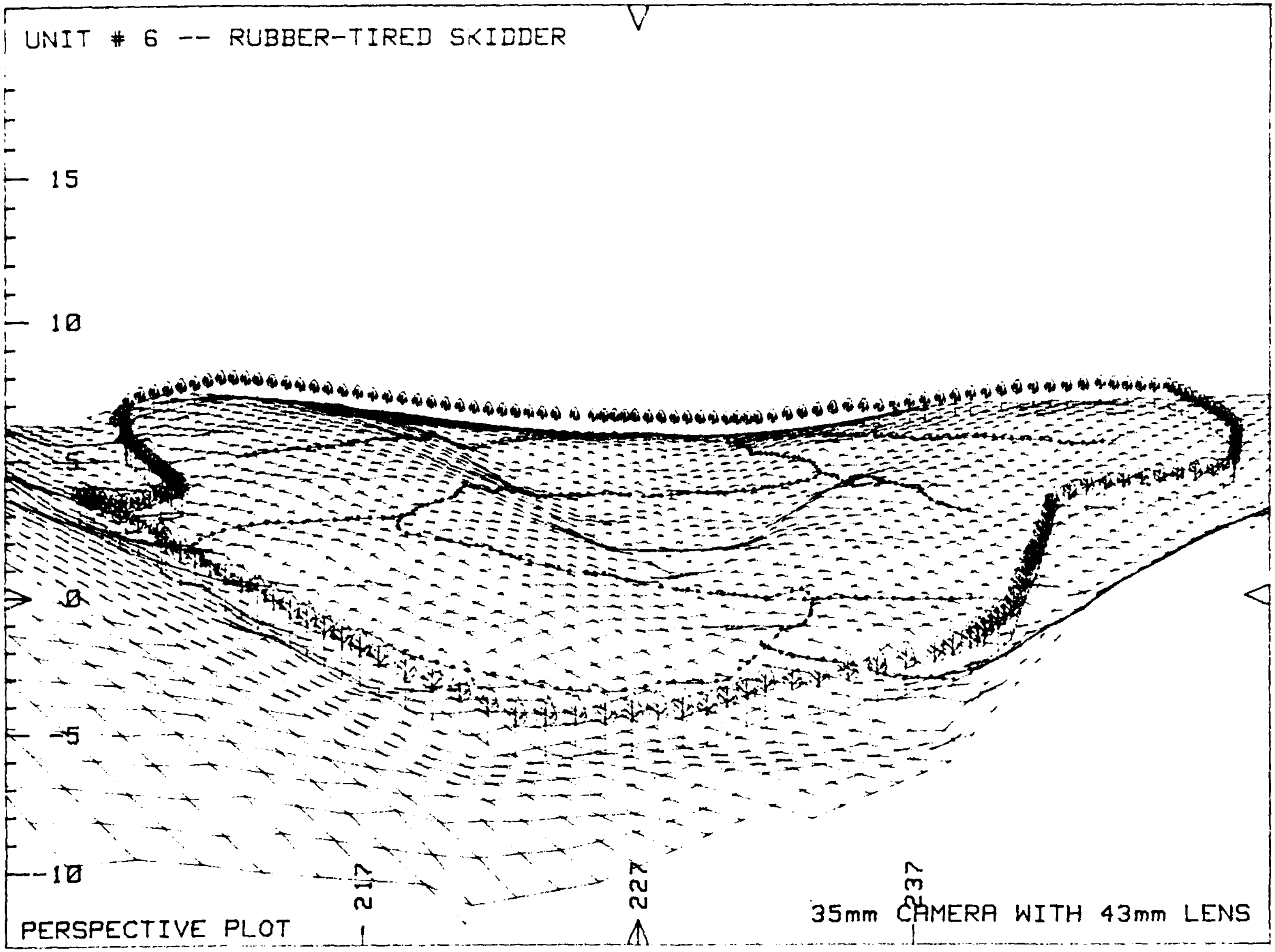

Figure 3.--Plot showing rubber-tired skidder road layout.

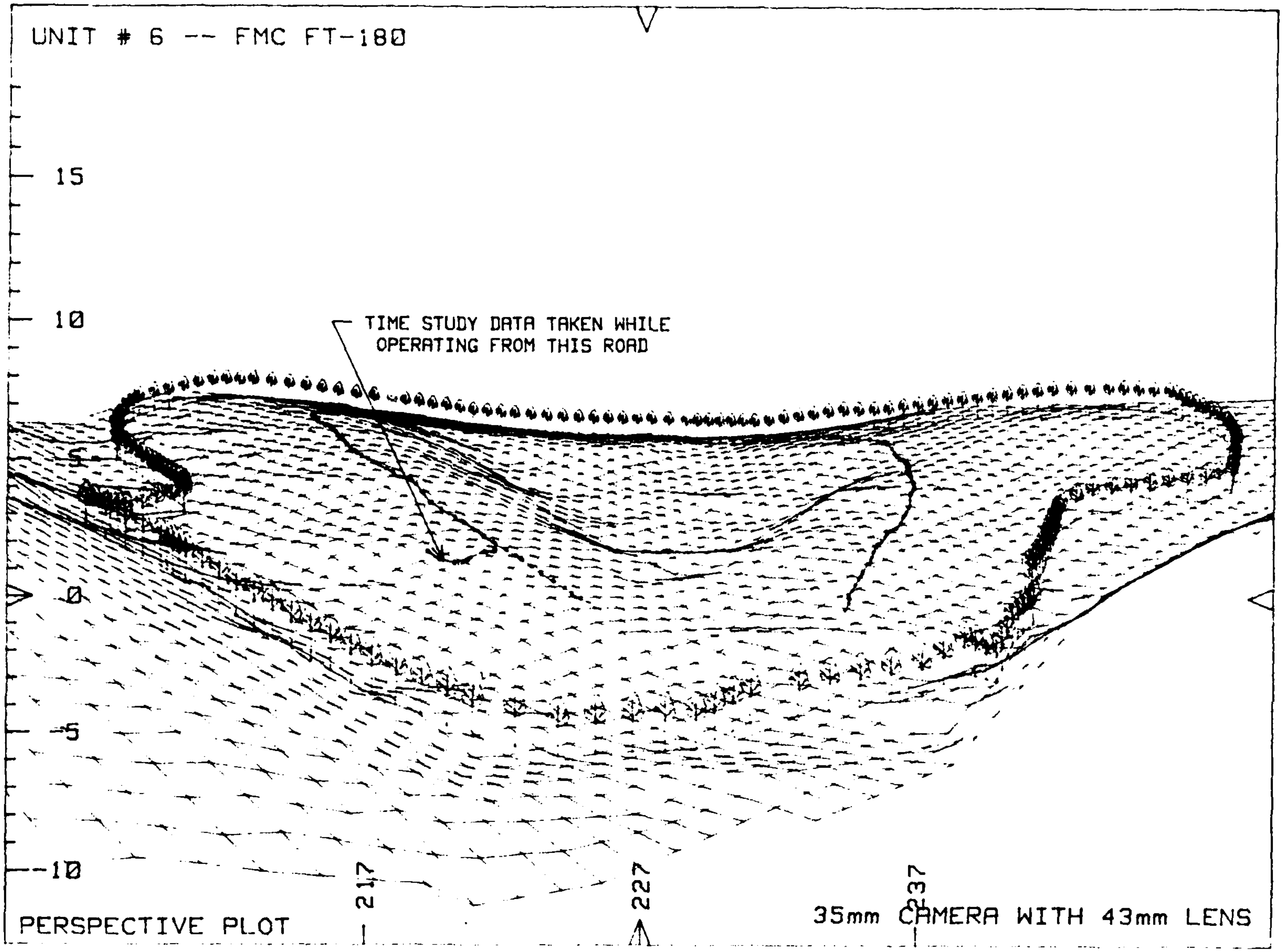

Figure 4.--Plot showing FMC road layout.

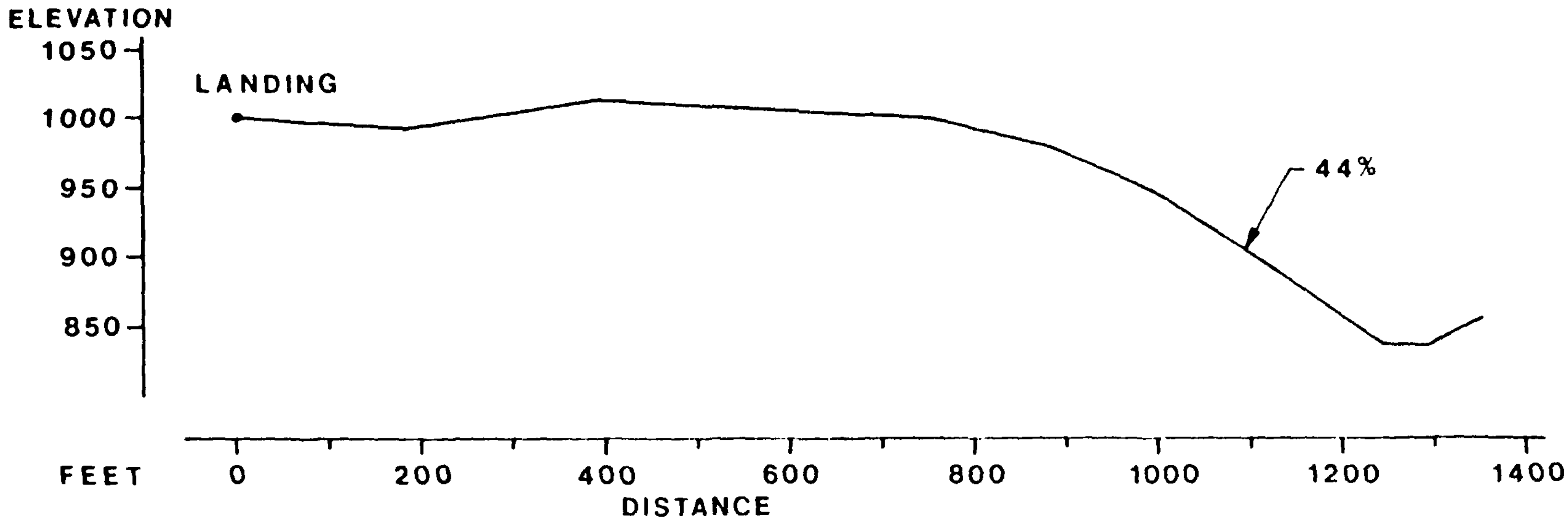

Figure 5.--Skid trail profile FMC FT-180CA tracked skidder.

Winch Lateral: (1) For large load of logs operator had trouble getting load on to FMC, (2) winch line came off drum, or (3) unhook part of load before proceeding to landing.

Travel Loaded: (1) FMC hung up on skidroad (high centered on a stump), or (2) winch load up steep section of skidroad.

Unhook: (1) Another machine in the way at landing, or (2) winch line twisted on drum.

General Delays: Delays not associated with an element time: (1) Pull tree down to be topped, (2) wait on trees at felling site, (3) personal operator, (4) FMC maintenance, or (5) get equipment for feller (saw, gas, or oil).

Two men were used to collect the time study and production data. One man at the hooking site collected the time study data away from the landing. The man at the landing used a walkie-talkie to tell the time study man when travel loaded and unhook ended. The man at the landing measured end diameters, length, and species of each stem brought to the landing for that cycle. Volume per cycle was calculated later by Smalian's formula.

DISCUSSION

The average values and standard deviations for the load and site variables are given in table 1. The range of skidding distance was from 850 to 1,550 feet because the skidloads with a short distance already were harvested. The developed equation reflects this range of skidroads and not the shorter skid distances. The number of chokersetters varied from load to load. The FMC operator always hooked chokers. The feller would help hook chokers when he was several trees ahead, and a man from FMC sometimes would help hook chokers. The bucker at the landing always unhooked chokers at the landing.

The main advantage of this machine is its ability to operate on steep slopes with a minimum impact on the skidroad (figs. 6-7). Figure 6 shows the worst soil disturbance on the harvest tract.

Another advantage of the machine is its ability to operate on skidroads built along ridgetops. These roads require less construction and are less costly than skidroads built across side slopes. For this test, 42 percent fewer skidroads were required with the FMC. When the skidroads are put to bed, less seed and fertilizer are needed and less time is required to build water bars.

Table 1.--Average values and standard deviations of load and site variables

Item	Average [a]	SD	Minimum	Maximum
Volume/cycle (ft^3)[b]	102	42	32	224
Butt diameter (inches)	11.21	2.39	4	18
Trees/cycle (no.)	6.5	1.5	4	14
Chokersetters (no.)	1.88	0.72	1	3
Skidding distance (feet)	1,193	175	850	1,550
Winch lateral distance (feet)	76	21	25	100

[a] For 83 cycles.

[b] By Smalian's formula.

Figure 6.--FMC skidroad after several cycles. This is worst soil disturbance on the harvest tract.

Figure 7.--FMC-180CA track print on road; rut depth is approximately 4 inches.

Figure 8 is a frequency plot of cubic-foot volume per cycle. The graph is skewed to the right, indicating that the machine could have been loaded heavier on each cycle. But closer inspection of the data showed that there tended to be a limit that the machine could pull up the section of skidroad with adverse grades. The machine skidded 15 loads that exceeded 140 cu ft per load, of these, 8 had to be winched up the steep section of the skidroad. The machine could not get traction to pull the load. It was concluded that the operator was loading the machine near capacity most of the time. It took 41 minutes to winch these 8 loads up the steep slope section of the skidroad. At an average of 5 minutes per load, there was an increase in cycle time of 34 percent.

Table 2 shows average time and standard deviation for skidding cycle elements and delays with multiple regression analysis and variables that were significant at or below the 10 percent level. The following cycle time equation was developed:

$$\begin{aligned} \text{Cycle time minutes} &= 1.451 + 0.00587\ (\text{skid distance in feet}) \\ &\quad + 0.348\ (\text{No. of stems}) \\ &\quad + 0.0410\ (\text{cubic-foot volume}) \\ R^2 &= .56 \qquad \text{SE } 2.09 \text{ minutes/cycle} \end{aligned}$$

COST ANALYSIS

A cost analysis was conducted with time-study data and hourly cost information supplied by FMC (table 3).

Using the $49.58 hourly operating cost for the FMC-180CA, we have a daily machine cost of:

$49.58/hr X 8 hr/day = $396.64
Operator cost
$6.00 (includes benefits) X 8 = $48.00
Total machine cost
$396.64 + $48.00 = $444.64

Using the cycle time equation and assuming average values for slope distance, number of stems per cycle, and average cubic-foot volume per cycle, the average cycle time can be generated as:

$y = 1.451 + 0.00587\ (1193) + 0.348\ (6.549) + 0.0410(102)$
Average cycle excluding delays = 14.91 minutes
Average cycle time with delays = 14.91 + 2.35 = 17.26 minutes
Assuming 7.5 hours operating per day, the other 1/2 hour for maintenance

$$\text{Cycle/day} = \frac{\underline{7.5}\ \underline{\text{hr/day}} \qquad \underline{60}\ \underline{\text{min/hr}}}{17.26 \text{ min/cycle}}$$
$$= 26 \text{ cycles/day}$$

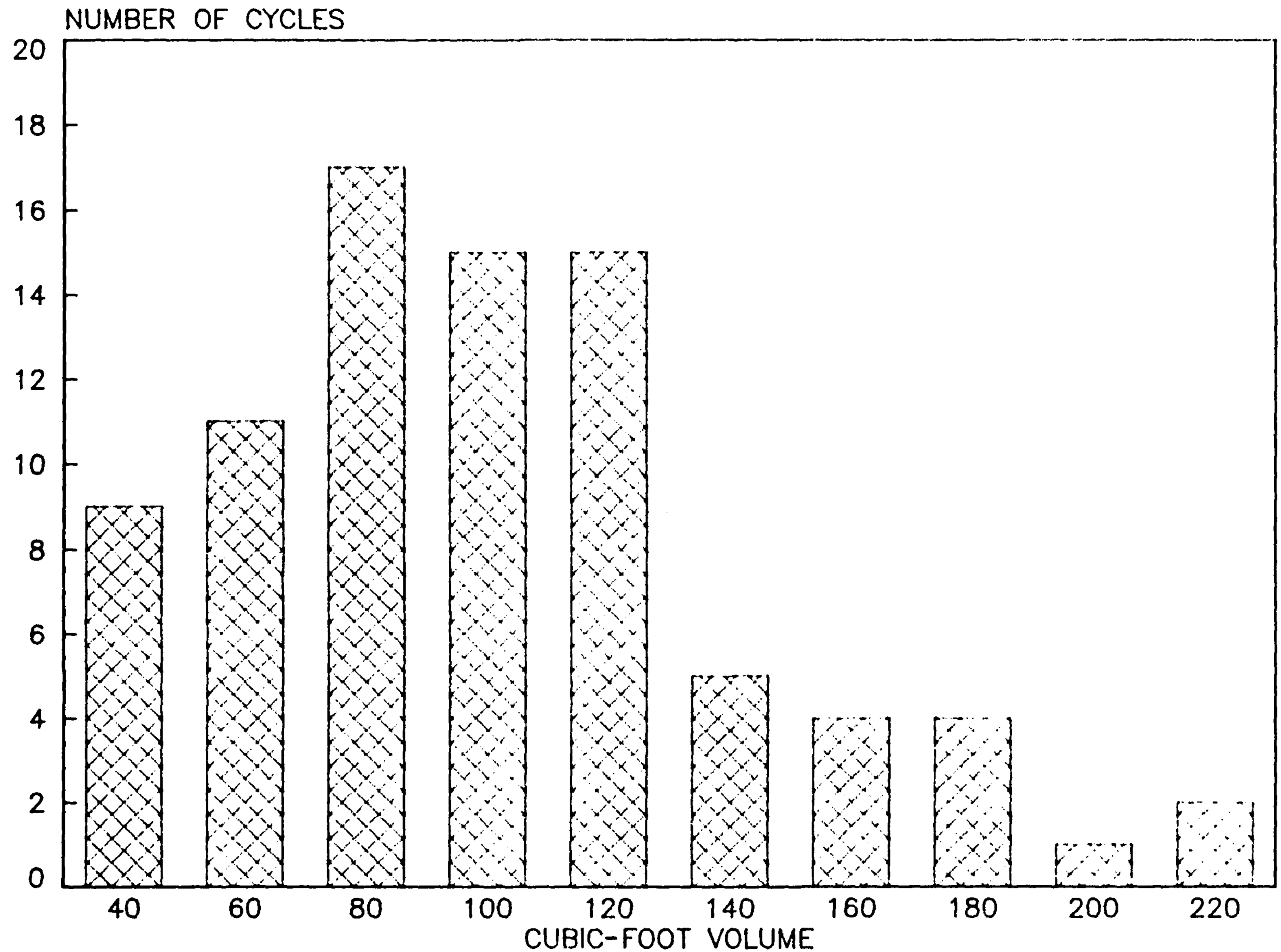

Figure 8.--Cubic-foot volume per cycle.

Table 2.--Average time and standard deviation for elements and delays in skidding cycle

Item	Average time a/	Percent of time spent in each element b/	SD	Minimum	Maximum
	Minutes			Minutes	
Travel empty	3.45	19	1.00	2	6.5
	3.82	21	1.24	1.65	8
Winch laterally	0.53	3	0.22	0.25	1.3
Travel loaded	5.78	35	2.20	2.6	14.0
Unhook	1.34	9	0.66	0.45	3.8
Cycle without delay	14.91	--	3.09	9.4	24.05
Element delay					
Per occurrence	3.44		--	0	12.4
Per cycle	1.16	7	--	0	12.4
General delay					
Per occurrence	2.25		--	0	10.0
Per cycle	1.19	6	1.96	0	10.0
Total delay/cycle	2.35	13	3.1	0	12.4

a/ Based on 83 cycles.
b/ Including delay time.

Table 3.--Owning and operating costs for FMC FT-180CA machine

Initial Purchase	
a. Annual usage (hr	1,600
b. Service life (hr)	8,000
c. Serice life (yr) (b/a)	5
d. Total delivered price (dollars)	135,000
less trade in value (if applicable)	35,000
e. Net depreciation value (dollars)	100,000
Hourly Owning Costs (dollars/hr)	
f. Depreciation (e/b)	12.50
g. Total interest, insurance, taxes (%)	24
h. Recurring charges on average invested capital $(g)\ \frac{(c+1)}{2c}\ \frac{(d)}{a}$	11.70
j. Total owning costs (f + h)	24.21
Hourly Operating Costs(dollars/hr)	
k. Fuel, GPH X cost (dollars/gal) 3.5 X $1.10	3.85
m. Maintenance	1.20
n. Basic machine repair	8.32
p. Undercarriage repair	12.00
q. Total operating costs (k+m+n+p)	25.37
r. Total owning and operating costs (j + q)	49.58

$$\text{Daily production} = 26 \text{ cycles/day} \times 102 \text{ cu ft/cycle}$$

$$= \frac{2652 \text{ cu ft}}{\text{day}}$$

$$= \frac{2652 \text{ cu ft/day}}{78 \frac{\text{cu ft}}{\text{cord}}} = \frac{34 \text{ cords}}{\text{day}}$$

$$\text{or } \frac{\$444.64/\text{day}}{34 \text{ cord/day}} = \$13.08/\text{cord}$$

From average values it was determined that daily production was 34 cords at a skidding cost of $13.08 per cord. The cycle time equation was developed from data obtained on the adverse grade skidroad.

Let´s assume the following:

1. No adverse steep grade on skidroad. FMC can average 180 cu ft per load.
2. Cycle time is 17.26 minutes (with delay) and travel distance is 1,193 feet (as given in tables 1 and 2).
3. Assume 7.5 hours/day or 26 cycles/day (without adverse road conditions cycle time should be less or more cycles per day).

$$\text{Daily production} = 26 \text{ cycles/day} \times 180 \text{ cu ft/cycle}$$

$$= \frac{4680 \text{ cu ft}}{\text{day}}$$

$$= \frac{4680 \text{ cu ft/day}}{78 \text{ cu ft/cord}}$$

$$= 60 \text{ cords/day}$$

$$\text{Daily cost same as before} = \frac{444.64/\text{day}}{60 \text{ cords/day}} = \$7.41/\text{cord}$$

Operating the FMC in adverse road conditions increases the cost of production from $7.41/cord to $13.08/cord.

CONCLUSIONS

The FMC-180CA logging vehicle will operate on slopes up to 44 percent, and move timber to a landing. Its cycle time averages 17.26 minutes for an average skidding distance of 1,193 feet. The average volume per cycle is 102 cu ft. Using a cost of $49.58/hour for the FMC, cost was calculated at $13.08/cord for skidding. Assuming some changes in variables and eliminating the effect of steep slope on load size, the skidding cost was calculated as $7.41/cord. Therefore, when laying out skidroads, place them in the area where they are the most favorable grade to travel loaded. If possible, lay out the roads so that travel loaded is downhill.

During the study period, the FMC spent 57 percent of its time in travel loaded and travel empty; 33 percent was spent hooking chokers, winching lateral, and unhooking chokers. The remaining 10 percent was spent in delays.

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FIELD EVALUATION OF MENZI-MUCK FELLER-BUNCHER

ON DIFFICULT TERRAIN IN SOUTHEAST ALASKA

by

Edwin S. Miyata
Charles N. Mann
Thomas L. Ortman

ABSTRACT

The Alaska National Interest Land Conservation Act (ANILCA) directs the USDA Forest Service to maintain a level of timber harvest of 4.5 billion board feet per decade from the Tongass National Forest in southeast Alaska. While the amount of standing timber appears adequate, harvesting is limited by problems associated with the lack of technically sound, economically efficient, and environmentally acceptable equipment and systems for use in the adverse logging conditions encountered in southeast Alaska. The frequent lack of suitable stump anchors, steep slopes, rocky terrain, shallow soils, and road systems contribute to adverse logging conditions. Research on the use of a climbing backhoe for commercial thinning, treatment of logging slash for wildlife habitat, scalping of salmonberry for tree planting, and installation of rock bolt anchors is described.

FIELD EVALUATION OF MENZI-MUCK FELLER-BUNCHER ON DIFFICULT TERRAIN IN SOUTHEAST ALASKA

Edwin S. Miyata
Charles N. Mann
Thomas L. Ortman[1]

INTRODUCTION

The Alaska National Interest Land Conservation Act (ANILCA) directs the USDA Forest Service to maintain a level of timber harvesting of 4.5 billion board feet per decade (approximately 450 million board feet from 18,000 harvest acres annually) in the Tongass National Forest (USDA Forest Service 1983). This cut could be limited due to problems associated with the lack of technically sound, economically efficient, and environmentally acceptable harvesting equipment and systems for use under the adverse logging conditions encountered in southeast Alaska. Some characteristics that contribute to adverse logging conditions are steep slopes; wet, shallow soils; muskeg; rocks; obstacles on the ground such as large old logs, root wads, and slash; and frequent lack of suitable stump anchors (Figure 1).

This paper reports results from a study designed to test, under southeastern Alaska conditions, a semi-walking machine called the Menzi-Muck.[2] It was believed that the machine would function well since it has been used for similar applications in the Lake States, North Carolina, and Washington. However, further study is needed to adapt the machine for forestry applications under the ever more severe conditions of southeast Alaska. This paper presents preliminary results for four different applications of the Menzi-Muck: (1) commercial thinning, (2) treatment of logging slash, (3) scalping of salmonberry for tree planting, and (4) installation of rockbolt anchors.

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[1] Edwin S. Miyata and Charles N. Mann, USDA Forest Service, Seattle, WA; and Thomas L. Ortman, USDA Forest Service, Portland, OR.

[2] Mention of trade names in this paper does not constitute endorsement of the product by the USDA Forest Service.

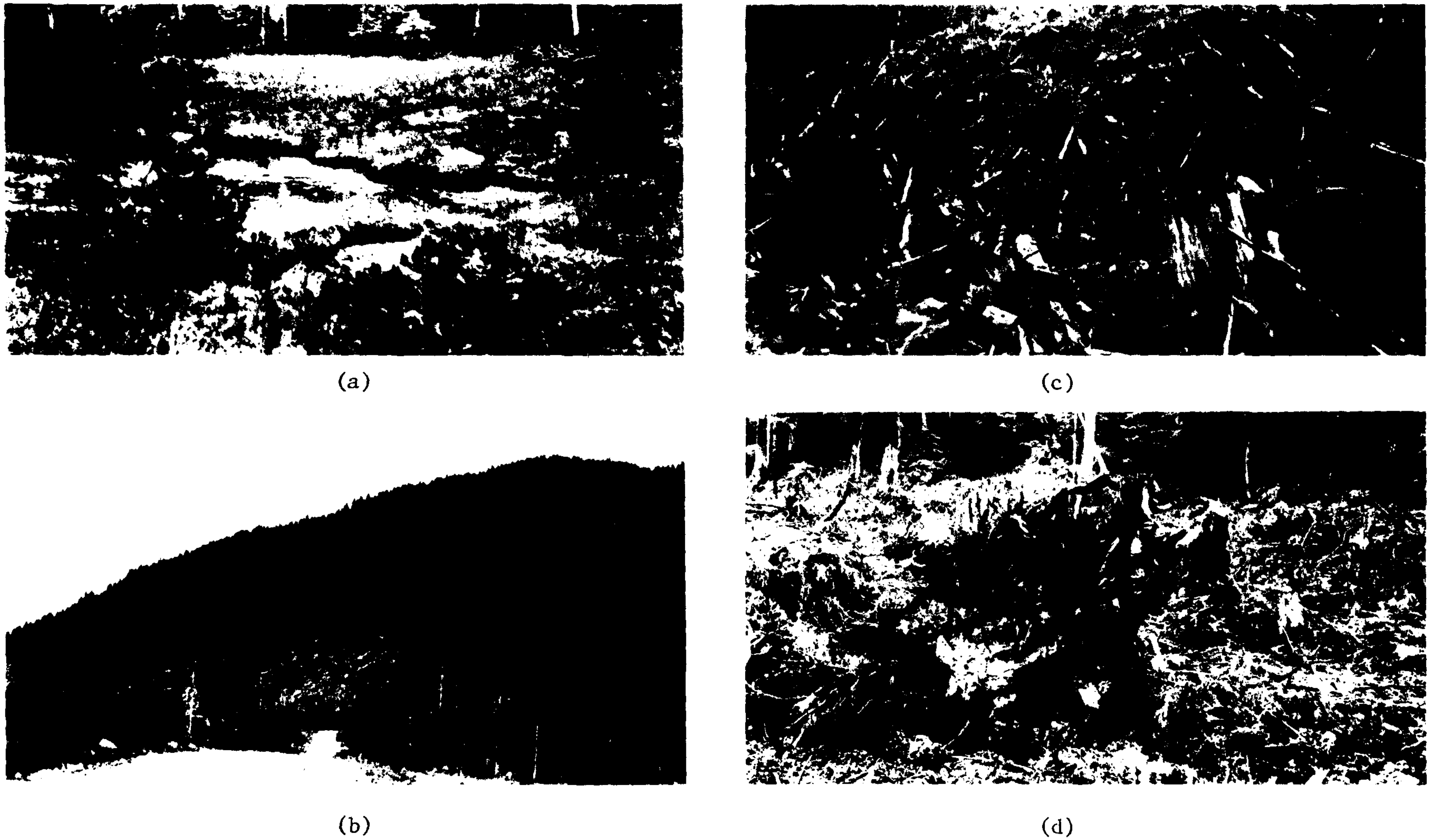
Figure 1. Typical logging sites in southeast Alaska.

(a) Muskeg

(b) Timber beyond the reach of highlead yarding (approx. 800 feet) is left without harvesting.

(c) Abundant logging residue

(d) Blowdown area



PREVIOUS STUDIES

As an all-terrain backhoe machine, the Menzi-Muck has been widely used in construction work on steep terrain, in streams, and on wet, soft ground in Europe for the last 20 years. In the United States, Arola et al. (1981) introduced the Menzi-Muck as a small tree feller-buncher on steep slopes in the Lake States. An initial field study of this machine was conducted on slopes up to 85 percent covered with 1 to 5 inches of snow. The authors reported a productivity of 59 stems per hour on a pole stand (clearcutting) and 101 stems per hour on a sapling stand (clearcutting). Deal (1981) studied the same machine in North Carolina and found that slopes had no significant effect on productivity for the Menzi-Muck. Schiess et al. (1983) conducted a study to evaluate the Kaiser-Spyder (functionally identical to the Menzi-Muck) in the State of Washington as a feller-buncher on slopes ranging from flat to 90 percent. The authors reported a productivity of 37 stems per hour on a red alder stand (clearcutting) and 62 stems per hour on a conifer stand (thinning). A specific logging machine that performs well at one location may perform poorly at a different location because of factors such as terrain, soil type, weather, and stocking density. Further study is needed to adapt the machine for forestry applications in southeast Alaska.

THE MENZI-MUCK MODEL 5000 T2

The Menzi-Muck is a small excavator developed for difficult worksites by Ernst Menzi A G of Widnau, Switzerland, during the late 1960's. Its versatility is due principally to its hydraulically adjustable legs and wheels, which can be raised or lowered, extended or retracted, or moved laterally. This movement of the basic components of the machine allows the Menzi-Muck to climb steep slopes or work in swamps or other difficult terrain.

The 5000 T2 model is powered by a 54-horsepower Hatz three-cylinder, four-cycle diesel engine. Hydraulic operating pressure is between 3,000 and 4,500 pounds per square inch (psi) at 34 gallons per minute. The rated lifting capacity of the knuckle boom is about 5,300 pounds. The longer reach and the maximum digging depth are 24 feet 11 inches and 17 feet 3 inches, respectively. The machine has a rated ground pressure of 5.4 psi with standard equipment and 2.4 psi with swamp attachment. The dimensions of the machine for transportation are 14 feet 9 inches long by 6 feet 11 inches wide, and it weighs 13,228 pounds. The wheel base is hydraulically adjustable from 6 feet 7 inches to 11 feet 6 inches. The model has hydraulically driven rear wheels, and a third small wheel allows rolling motion. The machine has a maximum rated speed of 7 miles per hour.

Field Testing

In summer 1983, the Pacific Northwest Forest and Range Experiment Station, Forest Engineering Systems (PNW-3701), Seattle, Washington, studied the Menzi-Muck 5000 T2[3] for felling and bunching and other applications under

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[3] Model 5000 T2 has 54 horsepower. The model EH used by Arola et al. (1981) and Deal (1980), a 40-horsepower engine.

conditions in southeast Alaska. The cooperators were the Alaska Region, Pacific Northwest Region, Ecology of Southeastern Alaska Forests research project (PNW-1652), San Dimas Equipment Development Center, all USDA Forest Service; Climbing Hoe of America, Ltd.;[4] and Tamrock Drill Company. All studies were conducted in the Tongass National Forest on Prince of Wales Island in southeast Alaska.

COMMERCIAL THINNING

For this test the Menzi-Muck was fitted with a 12-inch shearhead without an accumulator, designed and built by the North Central Forest and Range Experiment Station, USDA Forest Service, Houghton, Michigan. The specific objectives of this field test were as follows:

(1) Determine the productivity, cost, and operational characteristics of the machine.

(2) Document the quantity, type, size, and location of damage to residual trees caused by the machine's operation. These data and the follow-up investigation of tree damage will be analyzed to determine the development of defect and rate of healing. (This is an on-going study.)

(3) Determine the extent and severity of soil disturbance.

This preliminary report presents the results of objective (1) only. The results of the other objectives will be published in the future.

Site Description

The site for fully mechanized commercial thinning with the Menzi-Muck was located 2.5 miles from Winter Harbor. The terrain was uneven and contained very wet, soft soils with slopes ranging to 63 percent. Several small, sharp rocky ridges ran east to west through the unit. The soil was classified as Ulloa-Sarkar complex, and the surface layer was a grayish brown silt loam. Old growth timber on the site had been logged over 40 years ago and much logging debris remained including many old downed logs with diameters ranging from 25 to 45 inches, large root wads from blown down trees, and stumps with diameters up to 5.8 feet and heights to 5.7 feet. Logs often had to be bucked for easier movement of the machine. The site was occupied by a dense, even-aged stand of western hemlock and Sitka spruce which originated following logging of the old-growth timber. A preliminary survey indicated that the average age of the trees was 40 years. The stand contained 447 stems per acre in trees larger than 5 inches diameter at breast height (d.b.h.), and a basal area of 213 square feet per acre. The number of trees 1 to 4.9 inches d.b.h. totaled 2,275 per acre. Seventy-eight percent of the saplings were dead from suppression.

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[4] Now ACM Equipment Sales, Inc., Fayetteville, Georgia.

Results

The thinning method was based on previous studies (Biltonen et al. 1976, Arola and Miyata 1981), and consisted of clearcutting corridors for later cable yarding and selectively thinning the areas between corridors. Leave trees approximately 16 feet apart were marked with colored flagging that could be seen easily from all directions. As the Menzi-Muck proceeded into the stand, the operator cut a 16- to 18-foot wide corridor and removed all unmarked trees up to 15 feet in on each side of the corridor. A total of 455 trees larger than 1 inch were sheared by the Menzi-Muck and 47 bunches were formed between the standing trees. The gross production data for this commercial thinning operation are summarized:

Production Data

Total trees sheared	455 stems
Scheduled hours (with all delays) (SH)	17.7 hours
Productive hours (without delays) (PH)	9.8 hours
Machine utilization	55.0 percent
Productivity per SH	26.0 stems
Productivity per PH	46.0 stems
Total area thinned (approx.)	1.0 acre

The number of machine movements is generally affected by the number and spacing of the trees. The Menzi-Muck moved 90 times to shear and bunch the 455 trees. The average travel distance per move was 11.6 feet. It took about 3.4 minutes per move because the machine had to get around large downed logs, soft spots, and other obstructions. The site was thinned to a basal area of 111 square feet per acre. Figure 2 shows the area to be thinned and the Menzi-Muck operation.

The capital cost of equipment as obtained from a dealer is $75,000 in 1984. Based on field-recorded data and the assumptions made, the cost of using the machine was estimated to be $57.46 per productive hour excluding labor (Appendix A). Using the production data and machine rate, the cost of this mechanized thinning operation was estimated to be $1,641.44: $561.44 ($57.29 per hour x 9.8 hours) for the machine alone; $600.00 ($25.00 per hour x 24 hours)[5] for an operator; and $480.00 ($20.00 per hour x 24 hours)[5] for a sawyer to buck old logs on trees larger than 12 inches butt diameter.

TREATMENT OF LOGGING SLASH FOR WILDLIFE HABITAT

Slash debris left after logging is often dense enough to seriously hamper the movement of deer in logged units. Efficient access can allow maximum availability of forage for deer. The main purpose of this study was to evaluate the results of slash piling as it influences physical access by Sitka blacktailed deer to logged units. Specific objectives were as follows:

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[5] Assuming $25.00 per hour for an operator and $20.00 per hour for a sawyer, including fringe benefits. Each worker worked 8 hours a day for 3 days.

Figure 2. Commercial thinning.

(a) Area to be thinned.

(b) Menzi-Muck shearing a tree.

(c) Thinned area. Tree bunches along corridor.

(1) Determine the applicability of the Menzi-Muck for slash piling in terms of productivity, cost, and operational characteristics.

(2) Determine the effect of the slash piling on physical access of Sitka blacktailed deer to the study area.

(3) Investigate the response of the site to the disturbance of its litter layer by mixing litter and organic material into mineral soil during the machine's operation.

Disturbance of the soil surface cannot be evaluated for benefits to wildlife habitat until studies are completed at the Forestry Sciences Laboratory, Juneau, Alaska. The results of objective (3) will be published in the near future. This paper presents the results of objectives (1) and (2) only. A 4-foot grading bucket was attached for this operation.

Site Description

The slash unit is located on Prince of Wales Island approximately one mile from Winter Harbor. The site has a westerly aspect with many boggy areas scattered throughout. Slopes range to 40 percent. The soil was Ulloa-Sarkar complex and the surface layer was a grayish-brown silt loam. The site was logged approximately 2 years ago. Slash was unevenly dispersed. A fuel inventory was taken on a 4-acre area designated for treatment to measure the volume of slash present. The planar intersect method (Brown 1974) was used on 20 sample plots. The inventory showed 86.2 tons per acre of slash ranging from very small twigs and branches (0-3 inches) to logs ranging up to 50 inches in diameter with the heaviest concentrations in the 4- to 10-inch class.

Results

The Menzi-Muck traveled up and down the slopes removing slash from corridors 20 to 30 feet wide. The slash was either piled or windrowed in a manner which provided clear interspaces for deer movement throughout the study area. The slash was piled on existing stumps and logs whenever possible. All logs extending into areas to be cleared were positioned to lay parallel with the slope. The operator pulled slash in towards the Menzi-Muck with the bucket and then scooped up and deposited the slash in piles or windrows on either side of the corridors. Access was increased from below 25 percent of the area available to over 75 percent available for deer movements. Figure 3 shows the site before and after slash treatment.

The gross production data for this slash treatment for wildlife habitat are summarized:

<u>Production Data</u>

Slash treatment	129.3 tons
Scheduled hours (SH)	21.4 hours
Productive hours (PH)	15.2 hours
Machine utilization	71.0 percent
Productivity per SH	6.0 tons
Productivity per PH	8.5 tons
Total area treated	1.5 acres

Figure 3. Treatment of logging slash for wildlife habitat.

(a) Slash piling site before operation.

(b) Menzi-Muck moving large slash.

(c) Cleared pathway.

The machine rate was calculated to be $42.10 per productive hour excluding labor costs based on the field data and the assumption made (Appendix B). The cost of this slash treatment operation was estimated at $1,239.92: $639.92 ($42.10 per hour x 15.2 hours) for the Menzi-Muck; and $600.00 ($25.00 per hour x 24 hours)[6] for an operator.

SALMONBERRY SCALPING FOR TREE PLANTING

A very small but troublesome number of cutover acres have been taken over by salmonberry rather than regenerating conifers. Among the various scalping techniques, chemical treatment and hand scalping have been used in southeast Alaska. Chemical treatment often may be incompatible with other environmental objectives. Hand scalping has been done, but because of the very tough salmonberry root system only small areas have been treated and at great expense. A mechanical method would be an attractive alternative to reforest sites that were once very productive but are now occupied by salmonberry. Conventional equipment, however, operates poorly under the conditions encountered (numerous stumps, large fallen trees, and boggy areas). The main objective of this study, therefore, was to determine the applicability of the Menzi-Muck for scalping planting sites in salmonberry stands in southeast Alaska. The specific objectives for the application were:

(1) Determine the ability of the machine to traverse the stand and scalp planting sites.

(2) Determine the cost and productivity for mechanically scalping planting sites in salmonberry.

(3) Determine the impact on the soil in relation to nutrient status following scarification methods.

(4) Investigate the response of the salmonberry in reoccupying the scalped areas.

This paper presents the results of objectives (1) and (2) only. The results of objectives (3) and (4) will be reported in the near future.

A rake attachment, designed by the USDA Forest Service Equipment Development Center at San Dimas, California, was used in this operation.

Site Description

The site was located near the town of Thorne Bay. Ninety percent of the study site was occupied by salmonberry with a height of 5 feet. The site was logged in 1976 and had about 100 stumps up to 7 feet high and 5 feet in diameter. About 200 large cull logs were lying on the site. The soil was a mixture of Tonowek and Tuxekan. The maximum slope was 7 percent.

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[6] Assuming $25.00 per hour, including fringe benefits, 8 hours a day for 3 days.

Results

As the Menzi-Muck proceeded into the salmonberry site, the operator selectively scalped with the rake attachment on both sides of the machine's path. The size of scalps ranged from 4 x 4 to 6 x 6 feet, and the distance between scalps was 8 to 14 feet (estimated). The operator removed most of the salmonberry root system which was found at a depth of 4 to 6 inches. The scarification test site before and after operation with the Menzi-Muck is shown in Figure 4. The gross production data are:

Production Data

Total treated area	4.5 acres
Scheduled hours (SH)	20.8 hours
Productive hours (PH)	14.3 hours
Machine utilization	71 percent
Productivity	3.17 hours per acre
Operator time	24.0 hours

The machine rate was calculated to be $42.89 per productive hour (Appendix C). Based on the field data and machine rate, the cost per acre is estimated as:

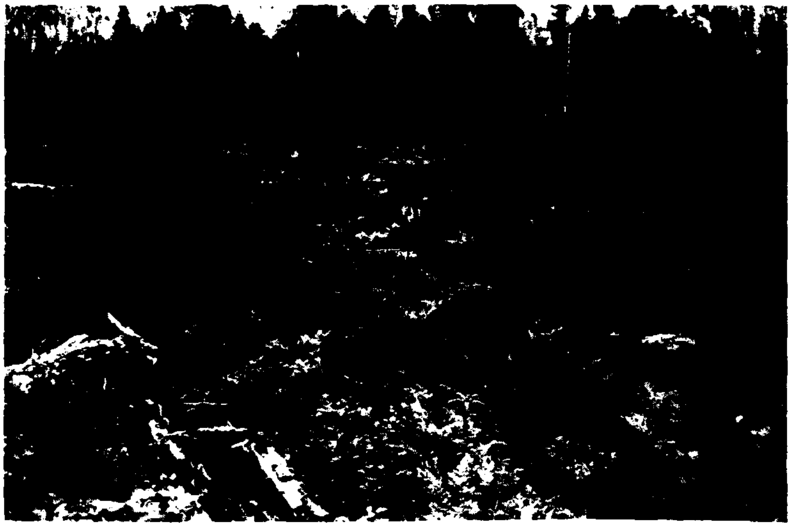
	Total Cost	Cost/Acre
Total machine cost ($42.89/hr x 14.26 hrs)	$ 611.61	$135.91
Operator cost ($25.00/hr x 24 hrs)	600.00	133.33
Total	$1,211.61	$269.24

ROCK BOLT ANCHORS

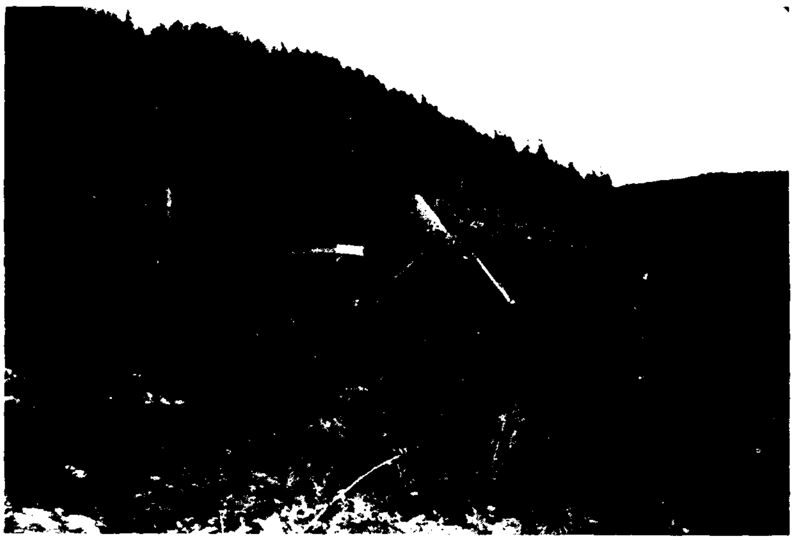
Strong and dependable anchors are required to withstand the tensions produced by the operating lines and the rigging of cable yarding systems. Stumps are the traditional means of anchoring cable systems. The diameter, however, of the trees decreases rapidly with elevation, and suitable stump anchors may not be available at the locations where anchors are needed in a logging operation. Selected substitute anchors need to be examined for their suitability in southeast Alaska. Rock bolt anchors have been widely used in mining and construction industries for many years. This technique, however, had not previously been applied to forestry operations in southeast Alaska. This paper presents the results of the first such field trials of rock bolt anchor installation.

Two different applications were tried on Prince of Wales Island. One was intended to replace an old deadman anchor of an A-frame used to transfer loads of logs from trucks to water at Winter Harbor Logging Camp. The other was for cable system tailhold anchors for the previously described commercial thinning stand. Both installations were successful.

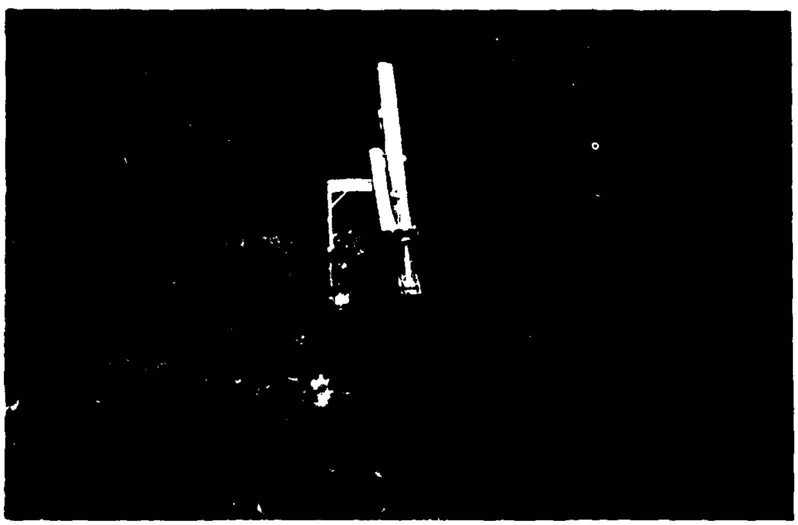
Figure 4. Salmonberry scarification.



(a) Area to be scalped.



(b) Menzi-Muck making scalps.



(c) Completed scalps.

Anchor Installation

Four rock bolts for anchoring an A-frame and two rock bolts for skyline tailholds were installed according to the procedure given by Ortman (1981) and Williams (1982). The installation procedure was as follows:

(1) Holes were bored 1 foot deeper (Figure 5) than bolt length and kept clean of debris.

(2) A bolt was slid into a hole.

(3) The bolt was torqued to set the anchor.

(4) The bolt was stressed to put it in tension and the rock in compression (Figure 5).

(5) A nut was tightened on a steel bearing plate to retain tension in the bolt.

(6) The bolt was grouted and the eye nut installed (Figure 5).

Results

The Menzi-Muck supplied hydraulic power to a Tamrock hand-held hydraulic drill, model HH50, for installing the A-frame rock bolts. Holes 1-3/4 inches in diameter and 9 feet in length were drilled horizontally into granite bedrock for 1 inch in diameter, 8-foot steel bolts. Average drilling time per hole was 20 minutes. A torque wrench was used to migrate the cone into the shell to expand the anchor, and the rod was then torqued to 500 foot-pounds. A hydraulic jack was used to tension the rock bolt. Each rock bolt was tensioned to 38,000 pounds which resulted in a load capacity of 152,000 pounds for anchoring the A-frame. Cost of material for each rock bolt was about $130.00.

A gasoline-driven rock drill/breaker, Pionjar Model 120 (weight = 57 pounds) was used for drilling holes for the tailhold anchors. Holes 1-3/4 inches in diameter and 6 feet in length were drilled horizontally in limestone bedrock for 1 inch in diameter, 5-foot bolts. A tripod support was used to drill straight horizontal holes to accommodate the head assembly of the rock bolts. Average drilling time was 30 minutes. Using a torque wrench and a hydraulic jack, each rock bolt was torqued to 500 foot-pounds and tensioned to 30,000 pounds. The cost of material for each rock bolt was about $123.00.

CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this first field test of the Menzi-Muck was to study its physical capabilities under conditions in southeast Alaska. The secondary objective was to measure the performance of the machine in terms of productivity and cost.

Figure 5. Installation of rock bolt anchor.

(a) Holes were drilled one foot deeper than bolt length and kept clean of debris.

(b) Tension in bolt with a hydraulic jack.

(c) Completed rock bolt anchors.

In commercial thinning, the productivity of 46 stems per productive hour that resulted is comparable with that achieved in previous studies. Considering the very difficult terrain conditions, we regard this as a good rate of production. The machine could travel over moderately steep slopes (up to 63 percent), large stumps, large downed logs, rocky areas, and gullies. Wet and soft terrain tended to slow the machine, especially when such terrain occurred often or was continuous. Mobility could be increased if the size of the teeth on the bottom of the shearhead was increased. Although the average d.b.h. was 7 to 9 inches, the trees were sheared at the stump, which was commonly much larger due to butt swell. A 14- to 16-inch shearhead with an accumulator would be preferable for this type of stand and would increase productivity. The operator was highly skilled in operation of the Menzi-Muck, but did not have any experience in forestry operations. Operators with skills in both areas are needed.

In slash piling, no major problems were encountered. Some minor problems were slash puncturing hydraulic hoses and pulling hoses from their fittings. Hydraulic hoses need to be shielded. The operator had a little difficulty getting slash to stay in the bucket and frequently lost part of the load. Modification to retain the load would increase the productivity.

In the salmonberry scalping, the Menzi-Muck was able to get around and over large debris. The rake attachment worked well for the scalping and for later tree planting. The only recommendation that we have for brush raking or similar jobs is that work should be scheduled for periods when brush is bare so that the operator can see cull logs and stumps.

For installing rock bolts, both the hydraulic rock drill and the gasoline-powered rock drill worked very well for drilling into granite and limestone bedrock. Total installation time could probably be shortened if the crew had more experience in drilling and installing rock bolt anchors. Before rock bolts can be fully implemented for skyline anchoring, more information is required concerning the reliability of rock bolt anchors in terms of such variables as the size of bolts, depth of embedment, rock characteristics, and holding capacity of the rock.

The machine demonstrated its potential to solve forest management problems by performing various tasks. The productivity and cost results presented should be used with caution, since this was the first field test of the machine under forestry conditions in southeast Alaska. Each individual task was studied only for a short period of time and on a small area, and the assumption had to be made for the machine rate calculation. The information, however, establishes baseline information to compare future studies or to develop and test new concepts. Future experience can provide data on the reliability and durability of the machine under similar working conditions.

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APPENDIX A

MENZI-MUCK MACHINE RATE

Description

Purchase price			
(f.o.b. delivered)	\$75,000		
Winch			
Shearhead (estimated)	8,000		
Tire cost	- 2,600		
Initial investment-P		=	\$80,400
Salvage value (20 percent of P) -S		=	\$16,080
Estimated machine life-N	3 years		
Working days per year	250 days		
Scheduled hours-SH per year	1,500 hours		
Utilization-U	67 percent		
Productive time-PH per year	1,000 hours		

Average value of investment: $AVI = \frac{(P-S)(N+1)}{2N} + S$ = \$58,960

Fixed Cost

Depreciation cost: $D = \frac{(P-S)}{N} = \frac{\$80,400 - \$16,080}{3}$ = \$21,440

Interest, insurance, taxes: = \$10,612.80
IIT = (12 percent + 3 percent + 3 percent) x AVI
Yearly fixed cost: YFC = D + IIT = \$32,052.80
Hourly fixed cost: HFC = YFC ÷ PH = \$32.05

Operating Cost

Maintenance and repair: MR = (100 percent of $\frac{D}{PH}$) = \$21.44

Fuel cost: $F = \frac{2.00 \text{ gal}}{\text{hr}} \times \$1.15/\text{gal}$ = \$2.30

Oil and lubricant-L = \$0.50

Tire: $T = \frac{1.15 \times \$2,600}{3,000/\text{hr}}$ = \$1.00

Hourly operating cost: HOC = MR + F + L + T = \$25.24
Hourly machine cost: HMC = HFC + HOC = \$57.29

APPENDIX B

MENZI-MUCK MACHINE RATE

Description

Purchase price			
(f.o.b. delivered)	\$75,000		
4' Bucket (estimated)	1,510		
Tire cost	- 2,600		
Initial investment-P		=	\$73,910
Salvage value (20 percent of P) -S		=	\$14,782
Estimated machine life-N	4 years		
Working days per year	250 days		
Scheduled hours-SH per year	1,500 hours		
Utilization-U	67 percent		
Productive time-PH per year	1,000 hours		

Average value of investment: $AVI = \frac{(P-S)(N+1)}{2N}$ = \$51,737

Fixed Cost

Depreciation cost: $D = \frac{(P-S)}{N} = \frac{\$74,510 - \$14,902}{4}$ = \$14,782

Interest, insurance, taxes = \$9,312.66

IIT = (12 percent + 3 percent + 3 percent) x AVI

Yearly fixed cost: YFC = D + IIT = \$24,094.66

Hourly fixed cost: HFC = YFC ÷ PH = \$24.09

Operating Cost

Maintenance and repair: MR = (100 percent of $\frac{D}{PH}$) = \$14.78

Fuel cost: $F = \frac{1.5 \text{ gal}}{\text{hr}} \times \$1.15/\text{gal}$ = \$1.73

Oil and lubricant-L = \$0.50

Tire: $T = \frac{1.15 \times \$2,600}{3,000/\text{hr}}$ = \$1.00

Hourly operating cost: HOC = MR + F + L + T = \$18.01

Hourly machine cost: HMC = HFC + HOC = \$42.10

APPENDIX C

MENZI-MUCK MACHINE RATE

Description

Purchase price			
(f.o.b. delivered)	$75,000		
Rake (estimated)	3,000		
Tire cost	- 2,600		
Initial investment-P		=	$75,400
Salvage value (20 percent of P) -S		=	$15,080
Estimated machine life-N	4 years		
Working days per year	250 days		
Scheduled hours-SH per year	1,500 hours		
Utilization-U	67 percent		
Productive time-PH per year	1,000 hours		

Average value of investment: $AVI = \frac{(P-S)(N+1)}{2N} + S$ = $52,780

Fixed Cost

Depreciation cost: $D = \frac{(P-S)}{N} = \frac{\$75,400 - \$15,080}{4}$ = $15,080

Interest, insurance, taxes: = $9,500.40

IIT = (12 percent + 3 percent + 3 percent) x AVI

Yearly fixed cost: YFC = D + IIT = $24,580.40

Hourly fixed cost: HFC = YFC ÷ PH = $24.58

Operating Cost

Maintenance and repair: MR = (100 percent of $\frac{D}{PH}$) = $15.08

Fuel cost: $F = \frac{1.5 \text{ gal}}{\text{hr}} \times \$1.15/\text{gal}$ = $1.73

Oil and lubricant-L = $0.50

Tire: $T = \frac{1.15 \times \$2,600}{3,000/\text{hr}}$ = $1.00

Hourly operating cost: HOC = MR + F + L + T = $18.31

Hourly machine cost: HMC = HFC + HOC = $42.89

PERFORMANCE OF TIMBCO HYDRO-BUNCHER ON STEEP TERRAIN

by

B.L. Lanford
B.J. Stokes

ABSTRACT

The timbco Hydro-Buncher has unique design features that allow it to fell and bunch timber on 60 percent slopes. The production of the feller-buncher was evaluated moving up-, down-, and across-slope and bunching up- and down-slope. The best productivity, 167 trees per productive machine hour, was achieved moving up-slope and bunching up-slope. The worst productivity, 127 trees per productive machine hour, was achieved moving down-slope and bunching up-slope. The Timbco Hydro-Buncher was capable of operating on slopes up to 60 percent with no loss of productivity.

PERFORMANCE OF TIMBCO HYDRO-BUNCHER ON STEEP TERRAIN

B. L. Lanford
B. J. Stokes

The Timbco Hydro-Buncher(1) is a machine of truly unique design (Figure 1). Notice the absence of a counter weight and that the engine is mounted between the tracks. These features put the center of gravity (CG) close to the ground. Slopes up to 60 percent are within the Timbco's capabilities.

Even if a machine is stable on steep slopes, an operator cannot effectively work on his side or back. With the Timbco, everything above the turn table tilts, which keeps the operator in a comfortable position on slopes up to 50 percent.

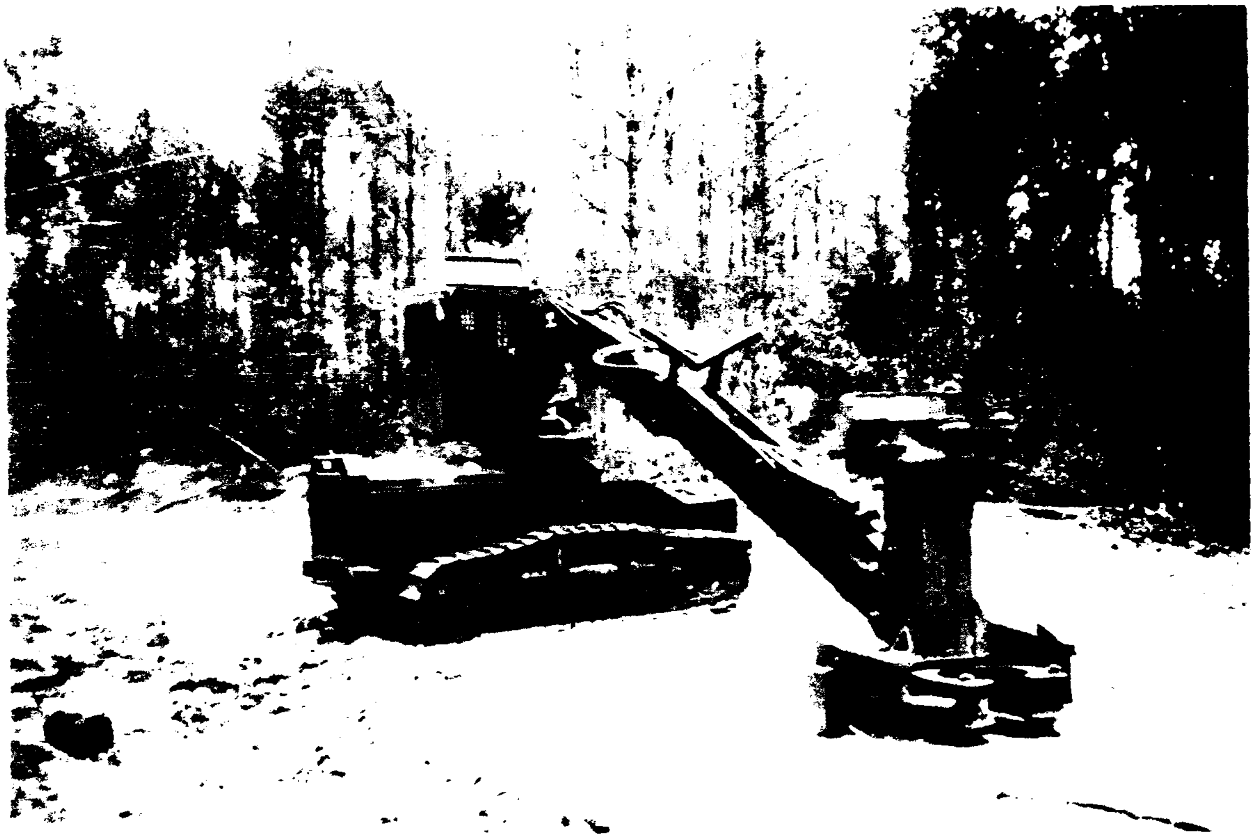
The machine was analysed in a thinning application. Its narrow width of a little over 9 ft and lack of tail swing allowed it to "fit" between residual trees. Hydrostatic drive gave the precise control needed to maneuver without damaging residual trees. The boom and felling head extend 23 ft from center line, but could tuck an accumulation within the width of its tracks so that cut trees could be placed behind the machine.

The machine tested was equipped with an 18-in shear head without accumulating arms. As with most feller-bunchers without accumulators, the operator was able to hold more than a single tree in the head. An optional 20-in head with accumulating arms is available. For those interested in cutting hardwood, the manufacturer recommends using the 18-in head but not shearing trees with stumps over 15 in.

An application which was tried, but not systematically tested, was delimbing. The holding arms of the felling head can be used to remove limbs from softwoods. Prior to shearing, the holding arms are placed around the tree at the highest point which can be reached. By raising the head to its maximum height with the holding arms lightly gripping the tree, limbs are cut off by the sharpened top edge of the holding arms. Limbs are removed to the maximum reach by bending the trees toward the machine. Lower limbs are removed by the bottom edge of the arms as the head slides down the bole to the shearing position. Of course, trees are limbed only to the maximum reach of the boom, which is 36 ft.

Authors are Associate Professor, Alabama Agricultural Experiment Station, Auburn University, AL and Research Engineer, Southern Forest Experiment Station, USDA Forest Service, Auburn, AL.

(1) The use of trade names is not an endorsement by Auburn University or the USDA Forest Service.



[illegible] Hydro-Ax buncher.

In addition to testing the effects of slope on productivity, the machine's agility permitted numerous felling patterns to be compared. Today, this paper will summarize our findings and give recommendations how this machine can be best applied. Our analysis and methodology are given in another paper (Stokes and Lanford, [illegible]).

STAND AND TERRAIN CONDITIONS

Time and production studies were conducted in an 18-year-old loblolly pine plantation located in west-central Alabama. Slopes ranged from flat (less than 15 percent) to steep (more than 60 percent). Test plots were thinned to 120 or 360 trees per acre from an initial stocking of 696 trees per acre (Table 1). The average diameter at breast height (DBH) of trees cut was 5.5 in and ranged from [illegible] to 1[illegible] in. Harvested volumes ranged from 7 to 23 cunits per acre and averaged 1[illegible] cunits. Leave volumes averaged 17 cunits per acre. Hardwoods were removed only for machine access. The stand was essentially free of hardwoods.

Table 1. Stand information summary.

Measurement	Initial Mean	Initial Range	Harvested Mean	Harvested Range	Residual Mean	Residual Range
DBH(inches)	5.9	1-12	5.5	2-10	6.4	1-12
Total height (feet)	49.4	3-64	48.0	30-61	50.8	3-64
Stem volume(1) (cubic feet)	4.2	1-19	3.4	1-14	5.2	1-19
Trees/acre	696	520-1,160	365	200-1,000	332	120-360
Volume/acre (cunits)	29.2	15-45	12.4	7-23	17.3	6-30

(1) Volume is solid wood to 3-in outside bark top.

FELLING PATTERNS

With the machine's ability to work in almost any direction, eight combinations of travel direction and drop locations were tried (Figure 2). Time and production studies were conducted: up-slope, down-slope, across-slope, and on level terrain. Sheared accumulations were placed in front of the machine and to the rear. When traveling across-slope, accumulations were placed up-slope or down-slope.

PRODUCTIVITY

A complete cycle was defined as an accumulation and included time elements of move-to-tree, swing-to-tree, shear, move-to-dump, swing-to-dump, dump, and bunch maintenance (Figure 3). A cycle began when the empty shear head left a deposited accumulation and continued until trees had been cut and deposited as the next accumulation. Since productivity should be expressed in per tree times, all times were summed by elements for each cycle and divided by the number of trees in the cycle.

Some of the elemental times were combined during the analysis. The feller-buncher did not perform all elements in every cycle; for instance, sometimes it was not necessary to move the machine before swinging to shear or move the machine before swinging to dump. Therefore, moving-to-shear and swing-to-shear times were combined, and move-to-dump and swing-to-dump were combined. Positioning of the shear head and shearing were found to be a constant time per tree, that is, not influenced by tree size; therefore, the shearing time was added to the move and swing-to-tree times. Finally, bunch maintenance was an occassional task which was not influenced by external factors; therefore, it was combined with dumping.

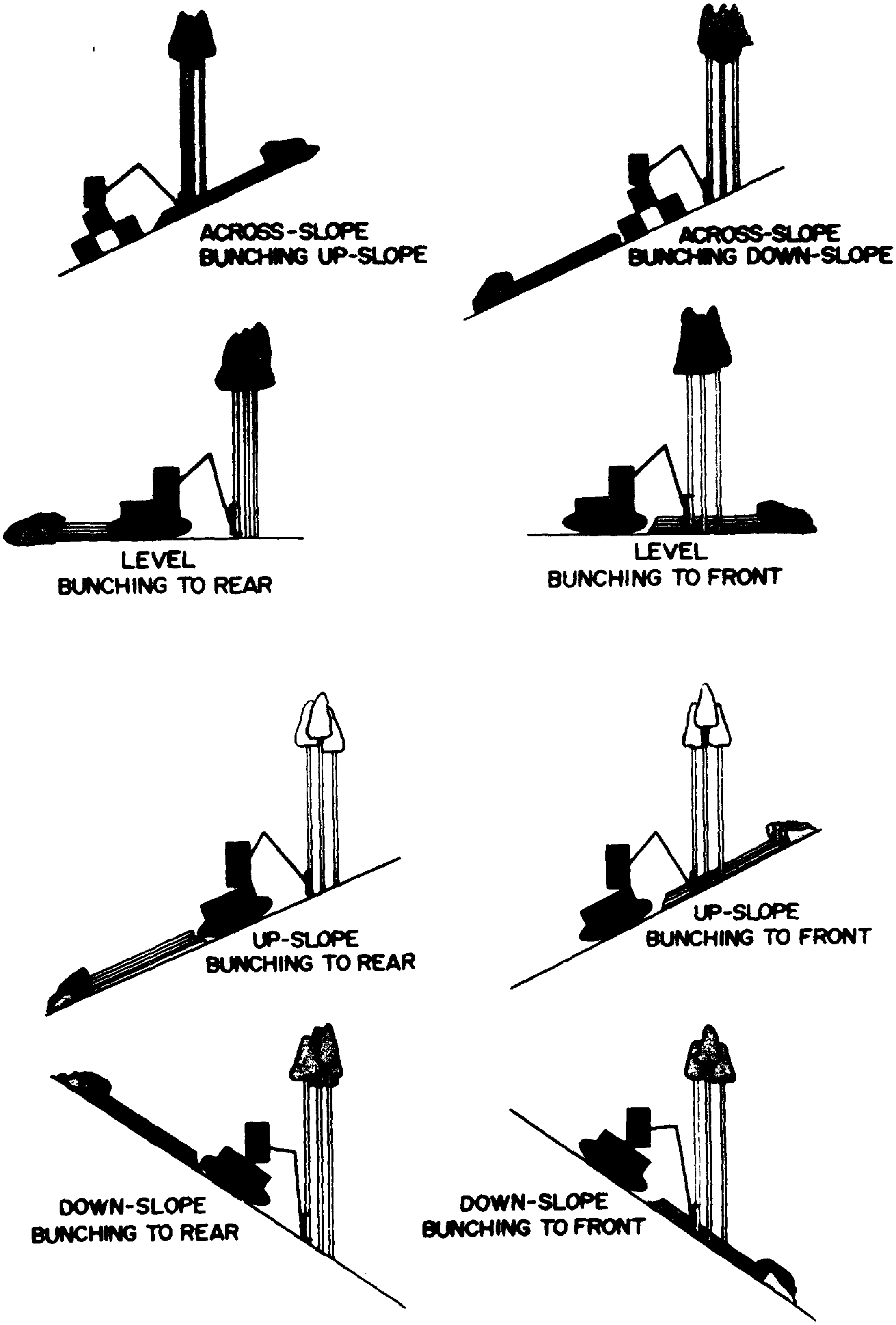


Figure 2. Felling patterns tested with Timbco Hydro-Buncher.

After combining times and dividing by trees per cycle, the following averages were determined:

Move, swing, and shear	0.26 min. per tree	(60%)
Move and swing-to-dump	0.09 min. per tree	(21%)
Dump and bunch maintenance	0.08 min. per tree	(19%)
Total productive cycle	0.43 min. per tree	(100%)
	or 2.33 trees per min.	

Through regression analysis, variables which might affect these times were tested (Figure 4). Measures of tree, stand, and terrain conditions and machine work methods were considered.

Time Elements	Combinations
Move-to-tree Swing-to-tree Shear tree	Move and swing-to-tree and shear
Move-to-dump Swing-to-dump	Move and swing-to-dump
Dump Bunch maintenance	Dump and bunch maintenance

Figure 3. Productive time elements for the Timbco Hydro-Buncher.

Tree factors

Tree factors included DBH, height, volume, and weight. Only the average DBH of an accumulation significantly affected the time per tree for swing and move-to-dump and dump and bunch maintenance. Time per tree increased for trees with larger DBH's.

Stand factors

Stand factors concerned the stand density of trees cut and left. Cut tree density influenced the time spent moving to and accumulating a payload, and residual density influenced the time to avoid the trees remaining after the cut. Density measures considered were trees, basal area, volume, and weight per acre. Cut trees per acre significantly affected the moving and swinging time when shearing or dumping. The residual trees per acre significantly affected the move and swing-to-shear time only. Low numbers of cut trees per acre increased the time per tree as did high numbers of residual trees.

Terrain factors

Terrain factors of slope, brush, and obstacles were considered. Unfortunately, extremes in brush and obstacles were not present on the stand used for the tests. As already mentioned, slopes up to 60 percent were present. Interestingly, slope did not affect the Timbco directly. There was a significant difference for the different patterns of which level ground was one category. Otherwise, the machine performed equally well on varing degrees of slope. This conclusion is a real compliment to the Timbco's designers and the operator's skill.

Variables	--- Productive element times per tree --- Move, swing, and shear	Move and swing to-dump	Dump and maintenance
Tree factors			
DBH		*	*
Total height			
Volume			
Stand (per acre)			
Cut trees	*	*	
Cut basal area			
Cut volume			
Cut weight			
Residual trees	*		
Residual basal area			
Residual volume			
Residual weight			
Terrain conditions			
Slope			
Brush			
Obstacles			
Machine factors			
Trees per accumulation			
Basal area per accumulation			*
Volume per accumulation			
Weight per accumulation			
Felling pattern		*	*

Figure 4. Conditions affecting productivity of Timbco Hydro-Buncher. ("*" identifies significant variables.)

Machine factors

Machine factors that were considered included number of trees, basal area, volume, and weight per accumulation. Also, the cutting pattern was a major factor which was tested. Of the accumulation measures, only the basal area in the head significantly influenced the time-to-dump. As the basal area increased, the dump time per tree decreased.

All eight cutting patterns had significantly different production rates (Figure 5). Assuming 150 residual trees per acre, 400 cut trees per acre, 6-in average DBH, and accumulated basal area of 0.39 sq ft, the highest production(167 trees per productive machine hours (PMH)) was achieved cutting up-slope and putting the bunches to the front. The slowest production(127 trees per PMH) involved cutting down-slope and placing the bunches behind the machine. These extremes have a difference of 39 trees per PMH or 1.5 cunits per PMH.

Considering the production rates of the different patterns, bunching to the front was more productive than to the rear. Also, extremes in production opposed each other. For example, to get

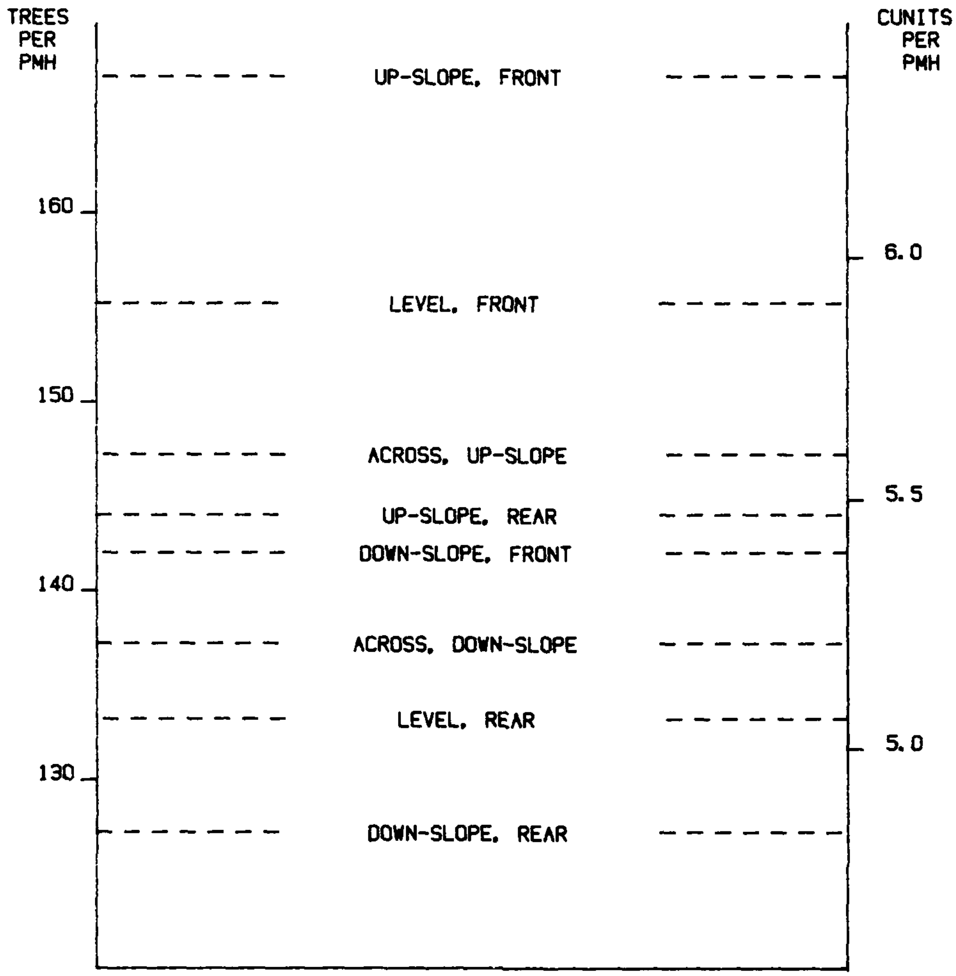


Figure 5. Production rates for felling patterns with Timbco. (Assume: 150 residual trees/ac, 400 cut trees/ac, 6-in DBH and accumulated basal area of 0.39 sq ft)

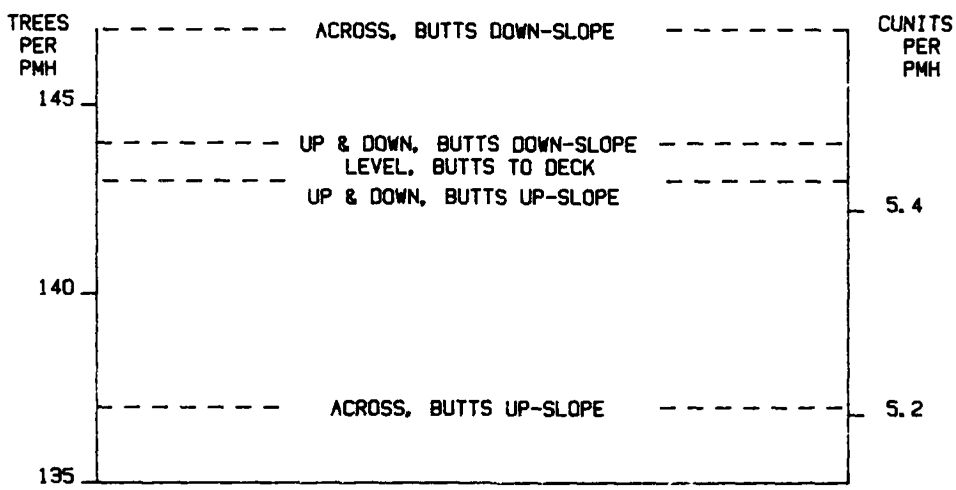


Figure 6. Production rates for combination felling patterns. (Assume: 150 residual trees/ac, 400 cut trees/ac, 6-in DBH and accumulated basal area of 0.39 sq ft)

maximum production up-slope by bunching to the front, you cause minimum production coming down-slope by bunching to the rear. This assumes you want the butts in the same direction. Also, keeping the butts in the same direction on level ground, you must penalize the high production when bunching to the front by bunching to the rear on the return trip.

It is understandable why it take more time to bunch to the rear. Bunching to the front involves less swinging-to-dump than bunching to the rear. This would be more pronounced in thinning because the operator has to tuck the boom tight to the cab when swinging to avoid damage to residual trees.

Assuming that it is not efficient to cut in only one direction, we combined patterns and re-examined productivity. It was assumed that as many trees would be cut in one direction as the other. Five combination patterns resulted as listed in figure 6: traveling up and down slope with butts up-slope, traveling up and down slope with butts down-slope, traveling across-slope with butts up-slope, traveling across-slope with butts down-slope, and traveling on level ground with butts faced to the deck.

Traveling across-slope with butts facing down-slope was the most productive (147 trees per PMH). Least productive was across-slope with butts up-slope (137 trees per PMH). Difference in extremes was 10 trees per PMH or 0.4 cunit. Maximum slope for these across-slope patterns was 30 percent.

A trend which emerged from these five combination patterns was that bunching uphill is more productive than bunching downhill. To match this pattern, bunches would be moved downhill in the subsequent function. Of course, downhill transport is limited to suitable terrain and soil conditions.

Another conclusion was that there was little productivity difference between up and down slope cutting regardless of whether the bunches were put uphill or downhill, nor was there a difference when cutting on level ground.

CONCLUSIONS AND RECOMMENDATIONS

1. The Timbco Hydro-Buncher was capable of operating on slopes up to 60 percent with no loss of productivity.
2. Average DBH of the trees in an accumulation significantly affected productive time per tree. Larger trees take more time.
3. Cutting more trees per acre decreased time per tree, and leaving fewer trees per acre also decreased the time per tree. Therefore, clear cutting is probably more productive than thinning.
4. Cutting up-slope and bunching to the front was the single most productive pattern, and cutting down-slope and bunching to the rear was the least productive.
5. To have continuous cutting, the most productive pattern involved cutting across-slope and bunching uphill with the butts facing downhill.
6. Finally, the Timbco is an effective tool for mechanically felling and bunching trees on steep slopes.

LITERATURE CITED

Stokes, B.J. and B.L. Lanford. 1983. Evaluation of Timbco Hydro-Buncher in southern plantation thinning. Winter Meeting ASAE, paper 83-1600, Chicago, IL, 11p.

THE USE OF WIDE, HIGH-FLOTATION TIRES FOR SKIDDING ON STEEP GROUND

by

Ernest Heidersdorf

ABSTRACT

The advantages of using wide, high-flotation tires for skidding in soft ground have been proven. However, they would also appear to have potential for other applications. This paper describes the Forest Engineering Research Institute of Canada's trials of such tires in the foothills of the Canadian Rockies. Their performance on steep-slope sites (up to 45%) in terms of productivity, fuel consumption, safety and ground disturbance is compared to that of "conventionally-tired" skidders.

THE USE OF WIDE, HIGH-FLOTATION TIRES FOR SKIDDING ON STEEP GROUND

Ernest Heidersdorf

The performance of off-road vehicles often depends on their flotation, that is, their ability to move on the soil surface without excessive sinkage. This machine characteristic is especially vital on the low strength soils, typically peats, clays and silts, which unfortunately underlie large portions of the forest area throughout Canada. In Canada, these soft-ground areas historically have been largely harvested in the winter months when the ground is frozen, but this practice presents problems in planning, scheduling, excessive inventories and subjugation to the whims of the weather. However, attempts to harvest these wet areas in summer with "conventional" logging tires have proved environmentally unacceptable and costly because of bogged down machines, reduced loads and excessive ground disturbance. Efforts to solve this problem with tracked vehicles have had only limited success, mainly because of high track and undercarriage maintenance costs.

To help resolve these problems, the Forest Engineering Research Institute of Canada (FERIC) initiated a search for a high-flotation tire that could be used to improve the performance of existing machines in soft-ground conditions. Testing commenced in 1980 with FERIC's introduction of 68-in. wide tires, manufactured and modified for us by Rolligon Corporation of Stafford, Texas, to skidding operations in the black spruce swamps of Northern Ontario. Ground conditions in this area consist of a thin root mat overlying deep organic soils of negligible shear and compression strength. It was hoped that the large footprint of the wide tires would keep the machines from breaking through the root mat.

The results were spectacular. Skidder productivity was increased by 60% because of the machines' improved flotation and the opportunity for increased loads and travel speed. Fuel consumption per unit of volume was reduced by 40% because more of the work effort was translated into production. Finally, but probably most importantly, ground disturbance was virtually eliminated resulting in a much improved regeneration chance.

These initial, positive results led to a four-year testing and development program by FERIC, the forest industry and several tire manufacturers culminating in a new breed of wide, flexible, low-pressure, high-flotation tires capable of significantly improving skidder performance in soft-ground applications. Besides the Rolligons, similar tires are now available from United Tire, Firestone and Goodyear with over 100 already in service in Canada.

While the main thrust of the wide tire program was to improve the range and capabilities of skidders in soft ground, it quickly became apparent that this new breed of tires possibly had potential for application in other areas. Their improved ride comfort may be beneficial in rough ground; in theory, they provide good traction and improved stability on slopes; and their low ground pressure should prove advantageous on sensitive sites.

To test these theories, FERIC purchased a set of United Tire 68x50-32 "Super Muskeg" tires for comparison with conventional practice in a number of applications across Canada. In 1983, the tires were shipped to St. Regis (Alberta) Ltd. in the foothills of the Canadian Rockies to assess their performance on both rough and steep terrain, mostly on clayey soils. FERIC, in cooperation with St. Regis, conducted a number of tests comparing the relative skidding performance of the United "Super Muskegs" to St. Regis' conventional 67x23.1-26 tires. Toward the end of the trial, the "Super Muskeg" tires were exchanged for a set of the newly-developed United "Super Swamper" tires and several of the tests were repeated. These tires, also 68x50-32, have somewhat more aggressive lugs than the "Super Muskegs".

All tests were conducted with the same two Timberjack 240D skidders, one for each set of tires. Prior to the trial, the relative inherent performance of the two skidders was assessed and they were found to be comparable.

TEST TRACK COMPARISON

These tests were conducted on side-by-side, straight tracks up a uniform 24% slope. A separate track was used for each tire/gear combination. The soil in the test area was a wet clay loam (29% sand, 43% silt, 28% clay).

Travel speed, fuel consumption and ground disturbance were assessed during each trip consisting of a 425-ft climb up the slope, a turn around and a return on the same track. The same operator was used for all the tests and the TJ 240D's traveled unloaded in each case. Fuel consumption was measured with Ruhl fuel meters mounted behind the cab of each skidder.

Table 1 summarizes the relative performance of the three tires during the test track comparison.

Travel speed with both the "Super Muskeg" and "Super Swamper" tires was about 16% greater than that of the conventional (67x23.1-26) tires with front chains and fuel consumption was reduced by 18%. During the 2nd gear test with the "Super Swamper" tires, travel speed was only 6% higher overall because of slip on 2 in. of snow which fell prior to testing. However on those runs without excessive slip, travel speed was again improved by 15%. At this slope, there was no appreciable performance difference between the two sets of wide tires.

TABLE 1: TEST TRACK COMPARISON

GEAR (Max. Throttle)	1 LOW					2 LOW				
TRIP NUMBER	1	2	3	5	10	1	2	3	5	10
PASSES	2	4	6	10	20	2	4	6	10	20
Conventional (FRONT CHAINS)				Stuck on 7 th Pass						Stuck on 11 th Pass
Speed, mph	2.07	2.05	2.01			3.39	3.37	3.30	3.13	
% of track with EMS*	2	7	10	10		0	4	10	26	26
Maximum sinkage, in.	19	21	22	30		10	15	17	20	22
United "Super Muskeg"										
Speed, mph	2.44	2.33	2.36	2.38	2.31	3.89	3.88	3.81	3.80	3.81
% of track with EMS	-	-	-	-	2	-	-	-	-	3
Maximum sinkage, in.	-	-	-	-	14	-	-	-	-	16
United "Super Swamper"										
Speed, mph	2.36	2.36	2.43	2.45	2.37	3.91	Slip 2.87	3.84	Slip 3.19	3.65
% of track with EMS	0	1	1	1	2	Not Assessed				
Maximum sinkage, in.	-	-	-	-	9					

* EMS = Exposed Mineral Soil

The wide tires' improved travel speed resulted from reduced ground disturbance (sinkage) and thus reduced slip and rolling resistance. With the conventional tires, the surface mat was soon broken and the tires spun out and bogged down in the clayey soil. Ground disturbance with the wide tires after 20 passes was less than that of the conventional tires after 4 passes. On sensitive sites, this reduction in ground disturbance yields benefits not only in travel speed, but also lessens the environmental impact, particularly on oft-traveled skid trails.

MAXIMUM SLOPE TEST

The purpose of this test was to assess the relative climbing ability (traction) and sidehill stability of the three sets of tires. A test track was laid up a uniform progressively steepening slope. For each tire/gear combination, the empty machine accelerated from a full stop at the bottom of the test track and attempted to climb as far up the slope in a straight line as possible. The travel distance to spin-out (or stall) and the slope at spin-out were recorded. For the stability test, the operator traversed the hill at progressively steeper slopes and the maximum slope at which he felt secure was recorded. The operator was a camp foreman with many years of skidding experience and, in our eyes, pushed the machines to their limit under the test conditions.

Ground conditions were wet for the conventional (front chains) and "Super Muskeg" tires, while one inch of wet snow fell prior to testing with the "Super Swamper" tires. Table 2 summarizes the results of the maximum slope tests.

TABLE 2: MAXIMUM SLOPE TEST RESULTS

T I R E	Conventional (67x23.1-26) FRONT CHAINS		"Super Muskeg" (68x50-32)		"Super Swamper" (68x50-32)	
GEAR	1 Low	2 Low	1 Low	2 Low	1 Low	2 Low
Ave. travel distance to spin-out, ft.	120	126	112	148	200	200
Slope at spin-out, %	28	28	28	34	40	40
Maximum sideslope*, %	30		40		44	

* The sideslope limits presented are specific to the test tires, machines and conditions. Since these limits may not necessarily apply to other situations, discretion is advised for the sake of operator safety.

The climbing ability of the conventional tires with front chains and the "Super Muskeg" tires was essentially comparable. The "Super Muskegs" had lots of rubber on the ground, but their light lugs did not grip adequately in the wet ground conditions. Traction was substantially improved with the "Super Swamper" tires, despite the dusting of snow, because of their somewhat more aggressive lugs.

Sidehill stability and thus operator safety was greatly enhanced when using the wide tires. Increased machine width extends the center of gravity away from the tipping fulcrum. Moreover, it decreases the angular roll when traveling over obstacles which becomes increasingly important at critical slopes. The "Super Swamper" tires performed somewhat better than the "Super Muskegs" because of their better grip.

PRACTICAL SKIDDING COMPARISON

The relative performance of the two TJ 240D's (conventional tires with front chains vs "Super Muskeg" tires) was compared during conventional tree-length skidding through detailed timing of the cycle time distribution. The machines worked as part of a <u>three</u>-man crew, both skidders going to a single faller. Travel empty was up an average 12% slope with some short 30% pitches. Travel loaded averaged about 1600 feet with some 300 feet of soft ground close to the landing. The two operators switched machines daily at lunch break to eliminate operator bias.

During the trial, travel empty speed was increased by 10% and travel loaded speed by 11% with the wide tires. Moreover, the necessity for winching during travel loaded was halved resulting in a 26% improvement in travel loaded speed overall. This improvement was achieved despite the fact that the operators did not use the wide tires to full advantage. They both tended to use the same skid trail and thus, the wide tires were handicapped by the ground disturbance largely caused by the conventional tires. Moreover, both took a circuitous route to avoid the soft-ground portion of the trail, even though the wide tires traversed this area several times without untoward difficulties.

In a subsequent trial, the relative performance of the tires in a <u>two</u>-man crew (single skidder per faller) was evaluated through detailed timing of the cycle time distribution during tree-length harvesting of two side-by-side strips. The two operators again switched machines daily at lunch break to eliminate operator bias. Travel empty was up a uniform 28% slope, while travel loaded ranged to 1000 feet.

Under these test conditions, travel empty speed was increased by 23%, travel loaded speed by 5% with the use of the wide tires.

These findings briefly outline FERIC's work with wide, high-flotation tires in steep-ground applications to date. Even though the degree of testing has been limited, the results provide an indication of the potential for such tires to improve skidder performance in mountainous terrain. In summary, the success of the new wide, flexible, high-flotation tires stems from a number of advantages they exhibit over conventional, narrow skidder tires, notably:

+ Potential for increased productivity and fuel savings per unit of volume because of the tires' low ground pressure, good traction and the opportunity for increased travel speeds.

+ Substantial reductions in ground disturbance (rutting) on sensitive soils, even after repeated passes, because of the tires' high-flotation characteristics leading to a decreased risk for erosion.

+ Less soil compaction providing improved regeneration and higher future growth rates.

+ Because of the more optimal use of the work effort, it may be possible to go to smaller machines to do an equivalent job, thereby again enhancing ground disturbance performance.

+ A softer ride for man and machine because of the tires' width, flexibility and low inflation pressure resulting in higher travel speeds and/or enhanced operator comfort and satisfaction.

+ Improved stability and thus safety on sidehills owing to the tire width.

+ Increased access to conventionally inaccessible timber because of the improved flotation and stability. On slopes, this may allow for the safe harvesting of blocks too steep for conventionally-tired skidders. This was the case at St. Regis where we were able to clear a block successfully where the operators had refused to work with their conventional machines. Moreover, the improved stability and reduced ground disturbance and compaction may permit operation on sensitive sites traditionally reserved for more costly cable yarding or tracked-vehicle systems. This is the brunt of a research project currently being conducted under a federal grant by MacMillan Bloedel Research on Vancouver Island. The results of this study should be of interest to those considering steep-slope applications.

+ This increased access can also mean less idle time for the skidder fleet and a reduced need for expensive specialized equipment.

Naturally, along with the benefits come a number of tradeoffs, notably:

- The high initial cost of the tires (double or more than that of conventional tires).

- The wide tires' performance in deep snow is questionable. Moreover, the tires are more susceptible to puncture in cold weather. Therefore, a change of tires with season may be required.

- The tire width places increased stress on the axle assemblies thus possibly necessitating the reinforcing of such especially on smaller-size class skidders.

- The increased vehicle width may affect manoeuverability, garage size and ease of freighting.

- The use of wide tires may require specialized equipment and facilities for tire maintenance.

- Their life, though appearing promising, remains as yet unproved.

Prospective users must weigh these advantages and disadvantages before choosing what is right for their particular conditions, needs and applications. However, there is no doubt that in the right application, the use of the new breed of wide, high-flotation tires can improve the range and capabilities of conventional skidders drastically.

MICROCOMPUTER SIMULATION TO AID SKYLINE LOGGING PLANNERS

by

Robert J. McGaughey
Harry G. Gibson

ABSTRACT

Timber harvest planners involved with cable logging operations are faced with problems concerning the effect of geographic features, access road location, and allowable system payloads on logging operations. These problems are especially critical in steep, mountainous terrain and excessively wet areas found in Appalachia where low value, low volume forests necessitate efficient yarding methods. A variety of small, highly efficient cable yarders have been used in the region but selecting the "best" system or system configuration for a given set of conditions is difficult and time consuming.

This paper describes a cable yarding simulation model designed for use by logging specialists as a pre-logging planning tool. The model is written for a Hewlett-Packard 9845B microcomputer and is compatible with other computer-based planning tools currently in use. The model uses readily available parameters descibing the yarding system, yarding area geometry, and stand conditions to predict the total number of turns, average volume per turn, average number of pieces yarded per turn, average cycle time, and the yarding cost associated with a yarding system. A test case is presented in which the model is used to compare two small cable yarders, one a design prototype and the other a commercially available yarder, for use in Appalachia. The results of the test case show that both yarders are suitable for use in Appalachia.

MICROCOMPUTER SIMULATION TO AID SKYLINE LOGGING PLANNERS

Robert J. McGaughey
Harry G. Gibson[1]

INTRODUCTION

Interest in cable logging as a potential yarding method for use in Appalachia is rapidly increasing. Decreasing timber supplies on easily accessible areas have forced logging planners to turn to the steep, rocky mountain slopes and excessively wet areas to meet the demands of eastern wood-using industries. These areas, previously considered unloggable, present several problems for timber harvesting equipment. The mountain slopes prohibit the use of ground-based yarding methods for safety reasons and the wet areas, dotted with deep potholes, discourage ground-based methods due to fall-through hazards. Cable logging techniques have been recognized as a feasible yarding alternative to help overcome these problems.

Cable logging is relatively new in the Appalachian region. Most experience with cable logging systems has been research oriented and intended to test the feasibility of cable systems. Early research has identified four characteristics found in Appalachia that favor cable systems, particularly the lighter, less costly systems (Gibson and Phillips, 1973):

1. 95 percent of the steeper slopes are predominently convex. Small cable systems are best suited to the short spans encountered on these convex slopes.

2. Most of the forest land in the region is held by non-industrial, private landowners. Also, forest land is contained in small isolated tracts. Small, highly mobile systems are capable of travel from tract to tract over existing roads.

3. Small, low value timber can be cost effectively harvested only with less costly cable systems.

4. The forest areas in question are relatively sensitive to site disturbances. The narrow roads required by small cable systems minimizes potential erosion and visual impacts of a logging operation.

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Because cable logging is relatively untested in the east, loggers and logging planners are hesitant to use cable systems. Equipment studies have shown that cable logging is a viable alternative to ground-based yarding methods but a means to determine the yarding cost associated with cable systems is needed.

This paper describes a cable yarding simulation model design to predict the cost and productivity of a given cable yarding system. Using this model, harvest planners can more easily evaluate cable yarding methods as an alternative to conventional ground-based yarding methods.

DESCRIPTION OF THE COMPUTER SYSTEM

The yarding simulation model is designed to run on a Hewlett-Packard 9845B[2] computer with 186 kilobytes of RAM. The model utilizes three peripherals:

1. HP-9872A four-pen plotter
2. HP-9874A digitizer
3. HP-2631G printer

The model can be used without these peripherals but some options within the model will not be available. Minor modifications to the model will permit the use of other peripherals provided they are compatible with the 9845B computer.

MODEL DESCRIPTION

The primary objective of the yarding cost simulation model is to predict the total number of turns, average volume per turn, average number of logs per turn, average yarding time per turn, and the yarding cost associated with a yarding system specified by the user. These approximations can, in turn, be used to compare various yarding system alternatives and configurations. The yarding cost model is designed to interface with PLANS (for Preliminary Logging ANalysis System), a package of computer programs designed to aid planners in preliminary planning of timber harvest units and access roads (Twito and Mifflin 1983). However, the model can operate as a stand alone program (McGaughey 1983) providing the user is prepared to calculate the average setting parameters needed for a simulation run.

The simulation model consists of an executive program and four subprograms: input, stand generation, yarding simulation, and report generation. The major advantage of using the executive program and subprograms is that the model can be implemented on computer systems with limited Random Access Memory (RAM). In situations where RAM is limited, i.e. less than 186 K, the executive program can reside in RAM at all times and each of the subprograms can be loaded from a storage device as needed. In this way, only the executive program and one of the subprograms reside in RAM at any one time. For execution on the computer system described earlier, the entire model can be held in RAM. A detailed description of the model as well as instructions for its use can be found in McGaughey (1983).

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[2]Mention of product names does not imply their endorsement by the authors.

Input Subprogram

The input subprogram is designed to query the user for the parameters needed to set up a run of the model. In general, the user is prompted for each parameter and, after all parameters have been entered, given two options: 1) editing the parameters or 2) running the model with the current parameter values. Model parameters are divided into four major groups:

1. System information--parameters describing the yarding equipment
2. Spatial layout information--parameters describing the geometry of the yarding area and the number of settings contained in the harvest unit
3. Stand information--tree size and spacing parameters for the stand to be harvested
4. General information--parameters that are specific to each run.

Throughout the model's development an effort was made to keep the data requirements to a minimum. Because the model is intended for planning purposes, some detail in the modeling has been sacrificed to allow the use of readily available, "low cost" parameters. The majority of harvesting simulation models currently available require extensive information concerning the distribution of elemental cycle times and log sizes. These models, while excellent for research applications, are not well suited to harvest planning.

Stand Generation Subprogram

The stand generation subprogram is responsible for creating a stand of trees to be harvested as well as felling and bucking the trees to obtain log coordinate, weight, and diameter information. In general, stands are created on an individual tree basis with the first step being to generate the tree's spatial coordinates. The overall arrangement of trees is controlled by the randomness factor for tree distribution, a number greater than or equal to zero and less than or equal to one, input by the user. Patterns of tree placement can be obtained ranging from trees arranged in perfect rows and columns using a randomness factor of zero to trees placed randomly on the area using a randomness factor of one.

A diameter class midpoint and felling angle are assigned to each tree to be used after a tree has been bucked to determine the location of the logs on the ground. The next step involves bucking the tree into logs based on minimum and maximum allowable log lengths and a minimum merchantable top diameter limit specified by the user. The logic used to buck a tree is designed to mimic the actions of a bucker working in the field by attempting to maximize the volume contained in large diameter logs rather than the volume contained in long length logs. After bucking is complete, it is a simple matter to fell the tree and determine the coordinates of the large end of each log. As the coordinates of each log are calculated, they are checked to see if the log lies within the yarding boundary. Only those logs whose large end is within the boundary will be considered for yarding.

Yarding Simulation Subprogram

The yarding simulation subprogram is responsible for simulating yarding activities to obtain production and cost statistics for the yarding system, stand conditions, and setting descriptors specified by the user. Output from this routine includes cost and production statistics and a file containing the following information for each turn: turn number, number of logs in the turn,slope yarding distance to the turn, lateral yarding distance to the turn, turn weight, sum of the log diameters in the turn, and the total cycle time for the turn. Individual turns are built by examining various combinations of logs until a suitable turn is found. As each turn is built, regression equations are used to calculate a cycle time for the turn.

It is important to note that the model pays particular attention to the spatial arrangement of logs on the simulated area while building turns. Because the model "knows" the location and size of all logs on the simulated area, the effect of the number of chokers flown and choker length can be carefully analyzed. Work with the model has shown that the number of chokers and their length significantly affect yarding system efficiency, particularly carriage loading efficiency. The small, low value timber characteristic of much of the Appalachian region necessitates efficient use of any yarding system, however the inherent high cost associated with cable logging (when compared to ground-based sytems) makes system efficiency particularly important.

Report Generation Subprogram

The report generation subprogram is structured to print the statistics generated by the stand generation and yarding simulation subprograms. The output subprogram can supply three types of output: an "echo check", an overall summary, and a detailed summary. The "echo check" reports the parameter values entered by the user during the input process. The overall summary reports individual turn statistics, cost and production summaries, and a brief description of the yarding system. The detailed summary reports all of the information contained in the overall summary along with distributions of turn weights, number of logs per turn, and cycle times. Additional information describing the yarding system used and setting conditions is also presented.

SIMULATION AS A PLANNING TOOL

During the model's development, one fact has become painfully obvious. Many time studies and associated regression analyses have been published describing the operation of all types of cable yarding equipment. However, the methods used to collect, analyze, and report the infomation have been far from consistent. The logging planner attempting to use these time studies to quantify yarding system productivity and cost quickly becomes discouraged and wonders if the studies have any application beyond the scope of the study itself. Problems caused by these inconsistencies are further magnified when we turn to simulation as a planning tool. To develop a model that produces accurate results based on parameters available to harvest planners becomes a difficult, if not impossible, task. A possible solution to this dilemma would seem to be a large scale evaluation of the existing regression equations.

However, variation among the methods used in the studies prevents any unilateral evaluation procedure. Perhaps a better solution would be a standardized "time study procedure" outlining types of data that should be collected, analysis techniques, and reporting methods. This would not correct problems with existing time studies but would make future studies more valuable. We are not suggesting a strict, inflexible procedure but rather guidelines that would allow the results of time studies to be combined with simulation techniques to provide a valuable planning tool.

TEST CASE

To demonstrate the model's application, consider a harvest planner faced with the problem of selecting a small cable yarder to operate in Appalachia. Several alternatives are available, but not all have been tested under Appalachian conditions. Therefore, it is desirous to utilize available data to evaluate alternative yarders. For this example, the model will be used to compare two small yarders suitable for eastern mountainous terrain:

1. Ecologger live skyline yarder mounted on a Tree Farmer C6D skidder
2. Prototype Peewee yarder mounted on a John Deere JD640 skidder

Both of these yarders are designed to yard small timber but only the Ecologger has been used in Appalachia. This test case will determine if the Peewee yarder could be used to yard the low volume, low value timber in the east.

Each yarder will be simulated on terrain providing adequate deflection for the system. The 23.5 acre area, shown in Figure 1, is characterized by an average maximum external yarding distance of 813 feet and an average chordslope of 50 percent. The maximum lateral yarding distance used for both systems was 75 feet. Specifications for the two yarders are shown in Table 1. Calculations using these specifications show that the load capability for both yarders should be about 4000 pounds over this terrain. The Peewee yarder was simulated on 10 parallel settings and the Ecologger on 3 landings with 5 skyroads from each landing. Stand conditions used for the simulation are summarized in Table 2.

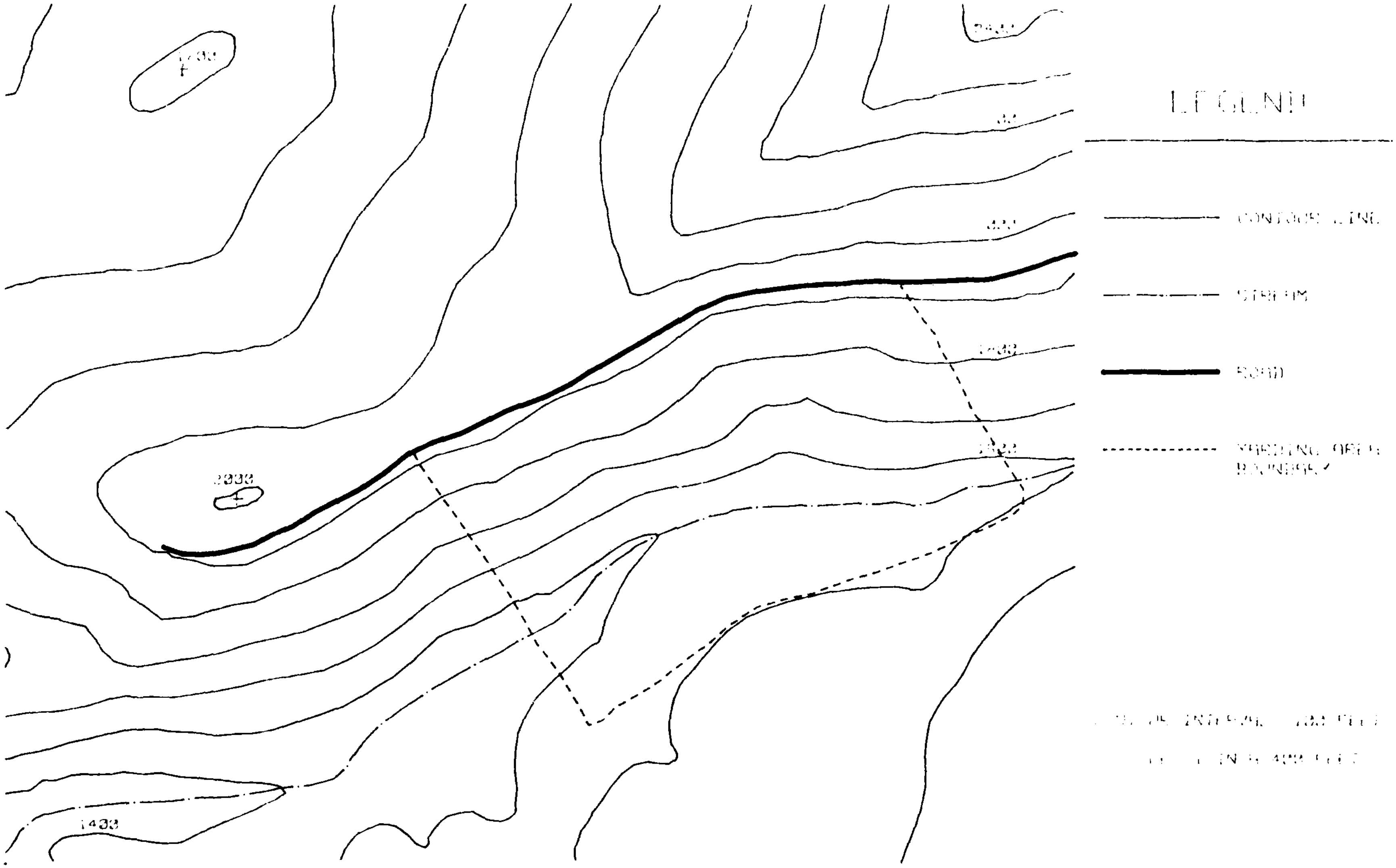

Figure 1. Topographic map showing the yarding area for the test case.

Table 1. Equipment specifications for the test case.

	Yarder	
	Peewee[3]	Ecologger[4]
Configuration	Running skyline	Live skyline
Horsepower	110	130
Tower height (feet)	37	42
Span capability (feet)	1200	1000
Lateral capability (feet)	150	150[5]
Working line	Haulback: 9/16"	Skyline: 11/16"
Machine rate[6]	$69.65	$70.42

[3] Peewee specifications taken from Mann and Mifflin (1979).
[4] Ecologger specifications taken from Fisher et. al. (1980).
[5] Lateral capability for the Ecologger was estimated.
[6] Includes fixed and variable costs (including labor) based on an 1800 hour working year.

Table 2. Stand conditions for the test run.

Diameter class midpoint(dbh)	Number of trees/acre	Volume/tree (Board feet, Scribner)
12.0	15.2	28
14.0	7.1	46
16.0	8.9	78
18.0	8.2	119
20.0	7.0	200
22.0	3.3	402
24.0	1.7	546
26.0	0.5	690
28.0	0.1	820
30.0	0.1	911
32.0	0.1	1002
Total volume per acre (Board feet, Scribner)		6695

Results

Results from the test case, shown in Table 3, show that the Peewee is about 27 percent more productive and 33 percent less costly than the Ecologger. While examining these statistics, it is important to note that Fisher et. al. report the crew operating the Ecologger had little cable yarding experience. Yarding costs can be expected to decrease to some figure close to that of the Peewee with an experienced crew. Also notice that the yarding cost in the test case is based on delay free-time. One can expect average cycle times to increase from 10 to 20 percent when delays are considered. With the addition of delay time, daily production will decrease and yarding cost will increase.

Table 3. Results of the test case.

	Yarder	
	Peewee	Ecologger
Average turn statistics:		
Weight	3135.46	3028.15
Volume (bd. ft.)	206.08	192.08
Number of pieces	1.69	1.56
Cycle time (minutes)[7]	5.19	7.88
Daily production (MBF)	13.10	9.51
Yarding cost (Dollars/MBF)	33.72	50.11

[7] Delay-free time

In addition to the application described in this paper, the model is well suited to evaluate the effect of the number and length of chokers flown for a given yarding operation. The efficiency of a yarding operation, particularly carriage loading efficiency, determines the cost of the operation. By simulating yarding activities with various combinations of choker length and number of chokers flown and studying the resulting distribution of turn weights, an optimum or near optimum combination can be found. Analysis of this type should result in "least cost" yarding methods.

CONCLUSION

Simulation techniques can be very useful in preliminary logging planning. This paper described a cable yarding simulation model designed to help planners evaluate cable yarding alternatives. A test case was presented showing how the model could be used to compare two similar yarding systems, one of which was tested in Appalachia and the other in the Pacific Northwest. Results of the test case show that the Pacific Northwest machine could be used in Appalachia and, in fact, may be be cheaper than the machine tested in Appalachia

Results from harvesting models and other planning tools can be used to aid planners in evaluating harvesting alternatives. However, the results of any planning tool should be tempered with judgement, experience, and perhaps even intuition. Hopefully, planning tools recently developed will allow the harvest planner to specify practices that will fully utilize, but not deplete, our timber resource.

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BREAK-EVEN ZONES FOR CABLE YARDING BY LOG SIZE

by

Chris B. LeDoux

ABSTRACT

The use of cable logging to extract small pieces of residue wood may result in low rates of production and a high cost per unit of wood produced. However, the logging manager can improve yarding productivity and break-even in cable residue removal operations by using the proper planning techniques. In this study, break-even zones for specific young-growth stands were developed with data from a field study, break-even analysis, and a simulation model called THIN. Results suggest that logging contractors can break even by developing and using residue removal guidelines for various combinations of piece sizes and slope yarding distances. Simulation analysis was used to explore the effect on production rates of slope yarding distances, piece size distributions, and numbers of pieces per acre. For the $76-per-hour machine used, the results of break-even analysis were most affected by piece size. Slope distance also had a strong impact. The number of pieces per acre had the least effect on production rates and costs.

BREAK-EVEN ZONES FOR CABLE YARDING BY LOG SIZE

Chris B. LeDoux[1]

Harvesting young, unmanaged stands creates large quantities of wood residue that could be used for energy (LeDoux and Adams 1983). Generally, this logging residue--tops and limbs, broken logs, old cull logs left behind from previous harvests, and standing and down unmerchantable species--has been left on the site and not used.

Recently there has been increased interest in using logging residue for energy to help diminish projected shortages of wood (USDA Forest Service 1981). To balance this desire against logging cost, product values, and landowner clean-up objectives requires a rigorous financial evaluation. The logging analyst must be familiar with the effects of site-specific variables on the cost of a particular logging operation and with the productivity of any proposed residue-removal venture.

Handling small pieces of residue or logs is a problem for the logging manager. Removing small pieces at long external yarding distances generally results in low productivity and high cost, much of which can be attributed to the use of expensive cable systems to extract the residue. One method for improving productivity is to use external yarding distance as a criterion for the removal of residue and to remove only larger pieces of residue if the yarding distance is long. However, decision-makers must know which variables affect cost and production and understand how those variables interact if they are to determine whether residue removal is economically feasible for a particular harvesting operation. Decision-makers must also be able to determine the total amount and minimum size of residue pieces that can be removed without sustaining a loss. In this article, the effect on production costs of slope yarding distances and piece size distributions is evaluated with a simulation model called THIN (LeDoux and Butler 1981) and a break-even contour is developed.

Although the specific example used here is a medium-sized cable yarder with a four-person crew operating in a corridor 1,000 feet long and 200 feet wide in Pacific Northwest Douglas-fir thinnings, the method could be used for any cable harvester removing residue from thinnings or clearcut harvests.

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USING THIN TO DEVELOP PRODUCTIVITY RATES

For skyline residue yarding, the THIN algorithm simulates the location and hooking of the first piece of residue and then the process of adding pieces to the turn. The simulation continues to add pieces to the turn as long as the skyline payload capacity is not exceeded, adequate chokers exist, and added pieces are not more than a specified distance from the first hooked piece (Fig. 1). The user can specify alternate external slope yarding distances and residue piece sizes as inputs to the model. The algorithm can then build turns and estimate hourly productivity rates for different slope yarding distances and statistical distributions of residue piece sizes.

The user should choose carefully the value used as the maximum distance from the first residue piece hooked to additional pieces; this value is an input to THIN. It is common practice for the hooking crew to pull line laterally from the carriage, hook one or more pieces of residue, pull line to additional pieces and hook them, yard the turn toward the skyline road, then stop and add pieces to complete the turn. The length of chokers flown can be one measure of the maximum distance the hooking line is pulled where choker length is increased slightly to reduce line pulling and effort by the hooking crew when building a turn.

In this simulation, we used a value of 43 feet for the maximum distance that the hooking line could be pulled from the first hooked log. This distance should not be confused with the maximum lateral distance allowed from the skyline; it is simply the maximum distance allowed from the first hooked log (LeDoux and Butler 1981). This distance was selected after detailed examination of turn distributions from field studies of residue yarding (LeDoux 1983, LeDoux and Adams 1983). The user can explore the costs and benefits of other distances simply by running additional simulations.

Data from a field test (LeDoux and Adams 1983) conducted in a young stand were used in this study to illustrate the effects of alternate slope yarding distances and piece size distributions on hourly production rates and costs. The simulation model was then employed to evaluate the effects of each variable on yarding productivity, by allowing that variable to change in value while holding the remaining variables constant.

Slope yarding distance

Generally, the farther out on the slope one goes to hook turns of residue, the lower the hourly productivity rate and the higher the cost per unit. Table 1 shows the effects of changes in slope yarding distance and average piece size on hourly production rates. In all cases, hourly productivity drops significantly as one goes farther out on the slope. For example, if piece size averages 6.0 cubic feet and slope yarding distance is 350 feet, the productivity rate is 273.82 cubic feet per hour.

Residue piece size and distribution

Generally, removing larger pieces improves productivity and reduces costs. For example, if we are yarding residue to distances of 650 feet and the average piece size is 6.0 cubic feet, the hourly production rate is 215.09 cubic feet. If slope distance remains unchanged but average piece size increases to 12 cubic feet, the hourly production rate increases by 89 percent, from 215.09 to 405.95 cubic feet (Table 1).

Table 2 shows the effect on hourly production rates of changes in the number of pieces of residue per acre in average piece size. Generally, the effect of pieces per acre on yarding production is less than the effect of changes in slope yarding distance or average piece size. For example, consider the hourly production rates when piece size averages 6.0 cubic feet and there are 100 pieces per acre and 400 pieces per acre. The hourly production rates are 247.38 and 266.12 cubic feet, respectively, an 8-percent increase. In contrast, yarding pieces that average 16.0 cubic feet at the same 100 and 400 pieces per acre results in only a 6-percent increase, from 582.41 to 619.72 cubic feet per hour.

BREAK-EVEN ANALYSIS

The break-even analysis does not consider move-in and -out or rig-up and -down costs, but focuses only on yarding costs and productivity. The analysis is based on the assumption that the hourly operating cost of the medium-size yarding machine and four-person crew is \$76 and that the residue is sold for \$35 per cord at the roadside as stacked firewood. The data in Table 1 are rearranged and shown in Figure 2. The objective is to find the maximum slope yarding distance for removal of residue of a given size at which market value and extraction costs offset each other and the operation breaks even.

The horizontal line that indicates the \$35-per-cord market value shows these combinations of average piece size and slope yarding distance. For example, at production costs of \$0.27 per cubic foot a logger could afford to yard 6.0-cubic-foot pieces no farther than 285 feet, and 8.0 cubic-foot pieces no farther than 571 feet. Although firewood products and prices are used in this example, similar analyses could be conducted for any product or price.

The data shown in Figure 2 can be rearranged to show the range of average piece sizes and slope yarding distances that would result in a break-even operation at each slope yarding distance shown (Fig. 3). The cross-hatched area shows the zone of economic profitability, while the unshaded area below the break-even line shows the area of economic loss.

The field manager and logging crew may find it difficult to analyze figures such as those developed above in the field; therefore, the next section describes how the data and results can be further rearranged for practical applications.

For a logging operation in a typical rectangular skyline corridor whose slope distance is 1,000 feet and lateral distance is 200 feet, the conditions we simulated, and a market price of $35 per stacked cord, the crew would be instructed to hook pieces 5.2 cubic feet and larger if the slope yarding distance is 0 to 200 feet, 6.2 cubic feet and larger in the 200- to 600-foot range, and only pieces 9.0 cubic feet or larger from 600 feet on. This policy would result in the operation breaking even, and hooking pieces larger than the minimums specified by zone would clearly result in profit.

Note that Figure 3 suggests that one should hook, for example, 8.0-cubic-foot pieces at a slope yarding distance of 600 feet; this holds true if slope yarding distance is broken down into the 100-foot-long short hauls shown on the x-axis of Figure 3. However, remember that our practical application assumes that the logger will deal with a slope yarding range of 600+ feet when he is matching piece size to slope yarding distance. Thus the size of the piece to be hooked should allow the operation to break even throughout the entire 600+-foot range, rather than within each of the shorter hauls that make up the total slope yarding distance.

Admittedly, it may be difficult for hooking crew members to determine rapidly whether a given piece contains 5.2 cubic feet, 6.2 cubic feet, or whatever the desired size might be for a given slope yarding range. However, given the desired volume of a piece, one can easily develop a matrix of mid-diameters and lengths that would yield the desired size (Fig. 4). A piece whose mid-diameter and length falls on or below the stairstep line (that is, in the shaded area) would be of the desired size and should be hooked. Similar matrices could be developed for alternate desired piece sizes. Ideally, the break-even analysis would be done before the actual logging operation. Clearly the method would not work very efficiently if the crew had to develop the break-even contours while logging.

CONSIDERATIONS FOR MANAGERS

Regional planners or forest managers may wish to develop break-even residue removal policies on a larger scale for wider application. Accordingly, the example data developed above could be arranged to develop contours, such as those shown in Figure 5, of zones where residue removal operations should break even. Such contours could be used by loggers, silviculturists, wildlife and fisheries biologists, and others involved in forest management who wish to visualize and evaluate the impact of alternate residue removal policies. The contours shown in Figure 5 consider only logging costs and firewood market values, but other concerns could easily be integrated into such an approach. Similar analyses could be developed for other yarders, crew sizes, or log size distributions. Break-even contours should be developed site by site or case by case to be most accurate and effective.

The method of break-even analysis presented in this paper will not answer all questions about residue removal, but it can aid decision makers in the financial evaluation of ways to remove residue from harvested stands.

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Table 1. -- Hourly production rate (in ft^3) as affected by changes in average piece size and slope yarding distance.

Slope distance[a] (ft.)	Average piece size (ft^3) 2.0	4.0	6.0	8.0	10.0	12.0	16.0
50	111.84	234.47	348.01	453.45	551.61	643.00	792.52
150	108.95	220.75	324.98	422.39	513.62	599.25	737.38
250	104.89	212.17	312.48	406.48	494.74	577.78	711.76
350	90.23	184.72	273.82	357.96	437.55	512.94	636.71
450	80.93	169.38	253.10	332.46	407.79	479.39	598.72
550	74.47	156.02	233.55	307.35	377.68	444.78	556.46
650	73.22	145.75	215.09	281.45	345.01	405.95	504.07
750	67.49	140.22	209.76	276.29	340.03	401.13	502.84
850	64.63	134.63	201.66	265.92	327.56	386.75	486.09
950	61.06	125.96	188.32	248.27	305.96	361.50	454.57

[a]Skyline corridor is 1,000 feet long and 200 feet wide.

Table 2.--Hourly production rate (in ft^3) as affected by changes in average piece size and number of pieces per acre.

Pieces per acre[a]	Average piece size (ft^3) 2.0	4.0	6.0	8.0	10.0	12.0	16.0
100	80.67	166.24	247.38	324.43	397.68	467.42	582.41
150	84.24	172.88	256.77	336.28	411.74	483.46	601.10
200	86.52	176.13	260.87	341.14	417.27	489.59	607.52
250	88.31	179.99	266.58	348.50	426.11	499.74	619.78
300	88.95	181.85	269.53	352.41	430.87	505.27	626.77
350	88.26	180.54	267.66	350.04	428.07	502.08	623.03
400	87.78	179.50	266.12	348.07	425.70	499.36	619.72

[a]Skyline corridor is 1,000 feet long and 200 feet wide.

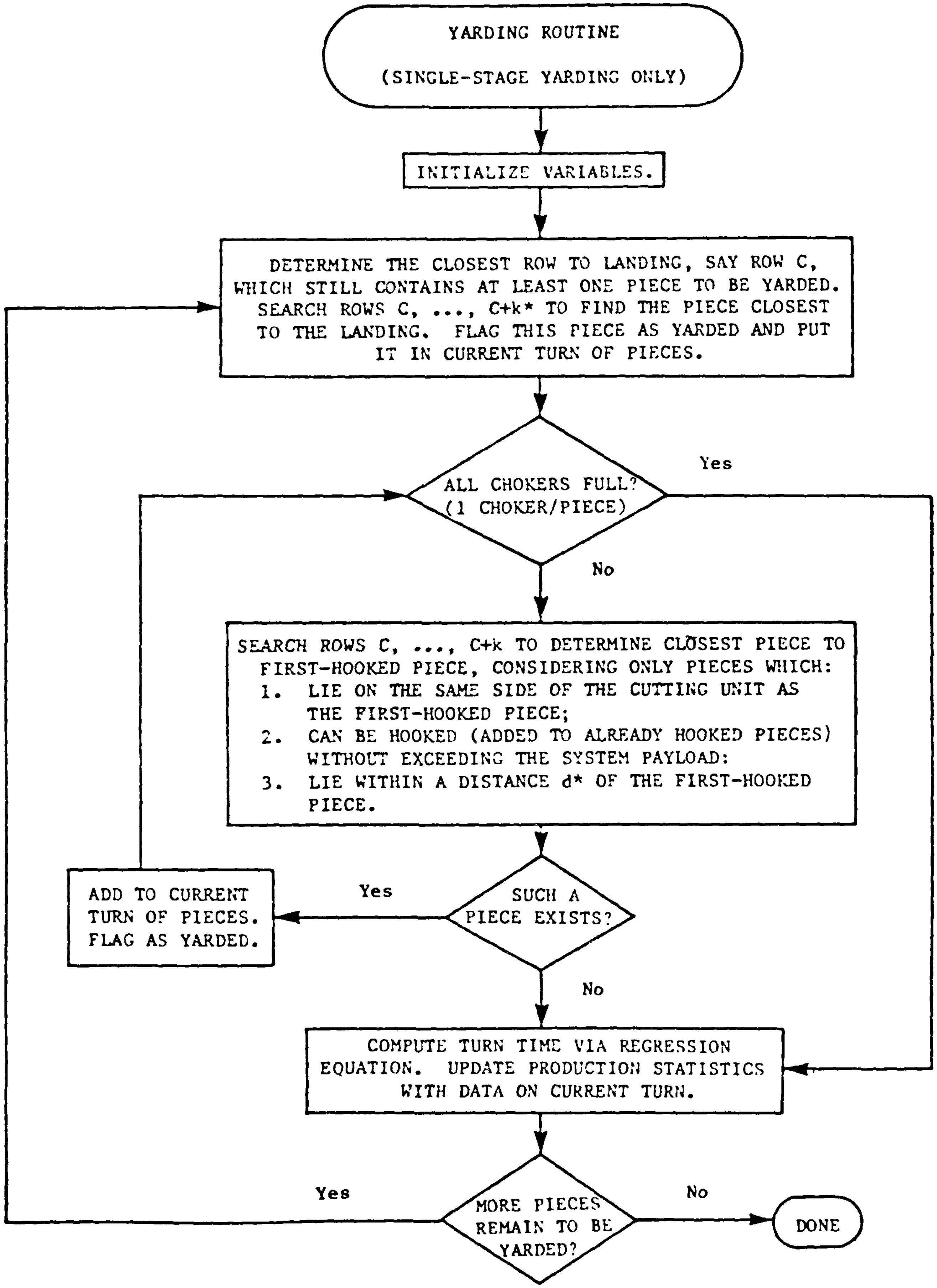

Figure 1.--Flowchart of THIN's simulated yarding routine (LeDoux and Butler 1981).

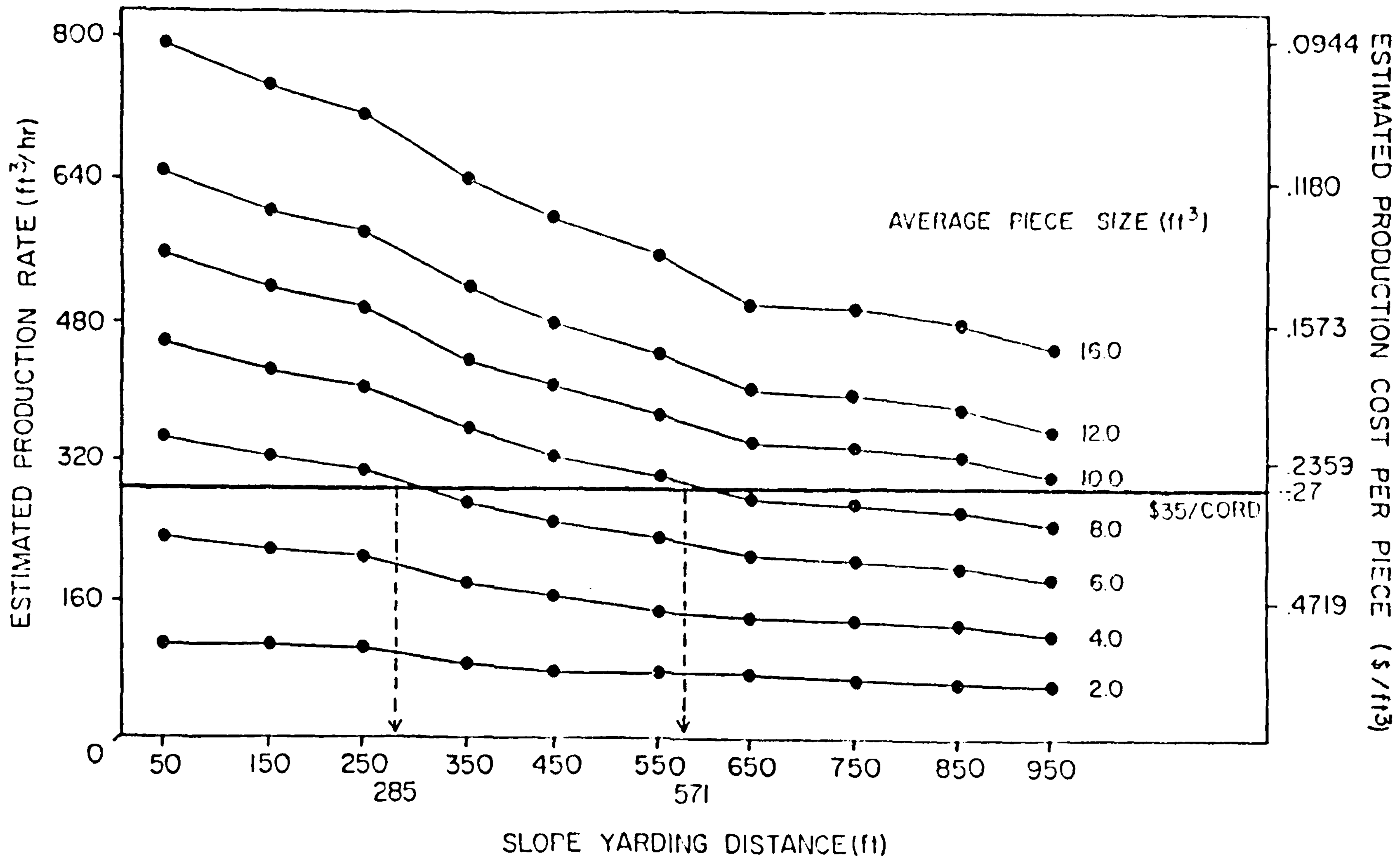

Figure 2.--Simulated production rates and costs of skyline yarding for various combinations of piece size and slope yarding distance. Horizontal line shows size/distance combinations at which operation would break even, assuming residue is sold for $35 per stacked cord and that machine and crew operating cost is $76 per hour.

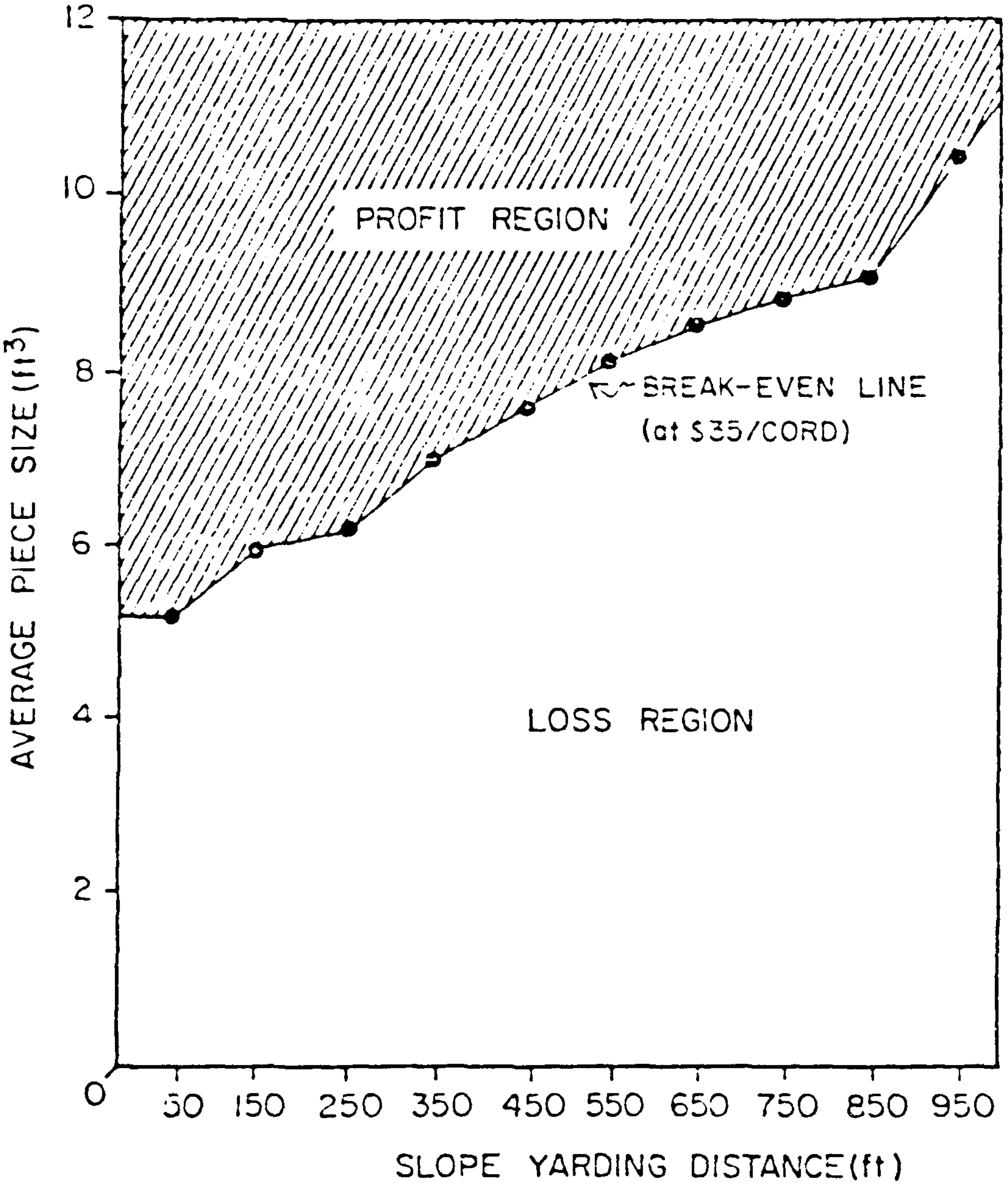

Figure 3.--Simulated economic regions and break-even line for cable yarding of residue that is sold for $35 per stacked cord. Cross-hatched area shows combination of average piece size and slope yarding distance that are economically feasible and yield a profit within each slope yarding distance shown; line shows size/distance combinations that allow break-even operation, and unshaded area (below line) shows size/distance combinations that yield loss. Skyline corridor is 1,000 feet long and 200 feet wide.

Volume of piece = 9.0 ft^3

$$\text{Volume} = C \cdot L$$

WHERE:

C = Basal area at piece's center

$$= 0.005454154\ D^2$$

D = Diameter at piece's center

$$= \frac{\text{Diameter of piece's large end + diameter of piece's small end}}{2}$$

L = Length of piece (in feet)

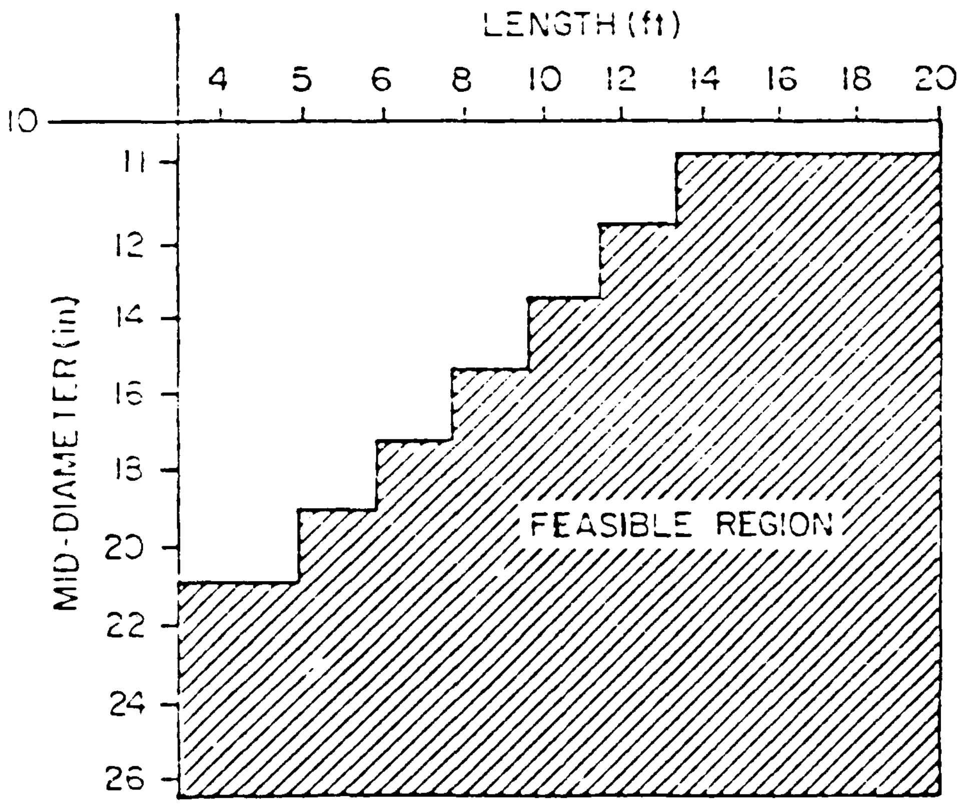

Figure 4.--Matrix of mid-diameters and lengths for residue pieces of at least 9.0 cubic feet. Piece is 9.0 cubic feet or larger if its mid-diameter and length fall on or below the stairstep line.

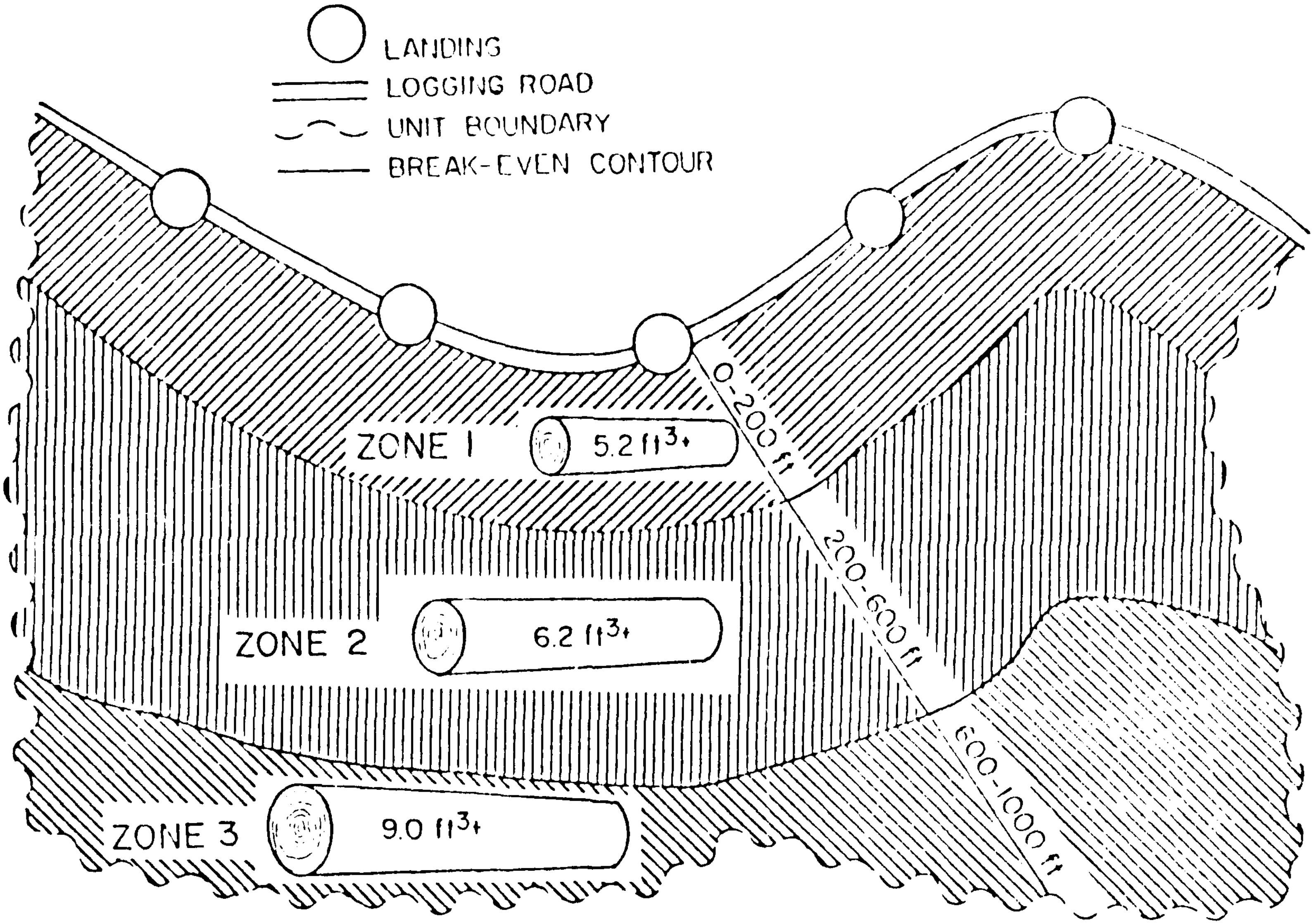

Figure 5.--Simulated contours of break-even residue removal zones for a typical skyline logging unit. Skyline corridor is 200 feet wide. In Zone 1, operator could break even removing residue pieces 5.2 cubic feet; in Zone 2, 6.2 cubic feet; and in Zone 3, 9.0 cubic feet.

THE INFLUENCE OF SITE FACTORS ON PRODUCTION COST PREDICTIONS FOR THE APPALACHIAN THINNER

G. Edward Wilson
David E. White
Cleveland J. Biller[1]

Abstract

Small cable yarding systems are considered to have great potential for logging small tracts in Mountainous terrain. One such yarding system is the Appalachian thinner. This paper describes an economic model designed to predict harvesting cost based on the capabilities of the Appalachian Thinner and the characteristics of the site. Actual and predicted harvesting costs are compared in order to evaluate the model.

Introduction

Logging operations in mountainous terrain are often unprofitable because of high road building costs and the inefficiency of conventional logging equipment on steep slopes. In the eastern United States the difficulties of logging steep slopes are compounded by the small size of the typical forest ownership. We have yet to find a logging system that is both profitable and environmentally acceptable under these conditions.

In response to this need Cleveland Biller designed a single drum cable yarder called the Appalachian Thinner (AT). Among the advantages of a single drum cable yarder are a relatively small capital investment, low operating costs, short set-up time, high mobility, and usefulness in partial cuts (Falk, 1980). Although the AT exhibits these advantages it would see limited application unless the cost and returns of timber removal are favorable (Biller and Peters, 1981). Furthermore, it is important that potential users of a new system such as the AT be able to base the investment decision on a reasonably accurate prediction of the net returns resulting from the adoption of the system. To put it in a different perspective, timber harvesting researchers face the challenge of not only developing new harvesting systems but also providing loggers with the decision-making tools required for a good choice among the systems available.

In an analysis of key indicators of successful logging jobs in the northeast, Herrick (1976) cited the need for investment planning based on the conditions under which logging is to be done. Of prime importance among these conditions are site factors such as slope yarding distance, board feet per yarding cycle, average number of logs per turn, and number of acres in the tract. Estimates of logging costs must therefore take these site factors into account in order to be accurate. Dependable predictions of

profitability require an analysis based on both the mechanical capabilities of the machine and the effect of site factors on cost of production.

After the prototype AT was developed, field tests were conducted on a clearcut, a sanitation thinning, and a diameter limit thinning. Regression analyses yielded equations which were utilized to predict cycle time as a function of slope yarding distance and number of logs per turn (Biller and Peters, 1981). Based on these regression equations, an economic model was then developed that incorporated several site factors into the prediction process (Wilson and White, 1981).

The purpose of the present study was to test the economic model in order to determine its accuracy in predicting the cost per thousand board feet (Mbf) of logging Appalachian hardwood timber under conditions for which the machine was designed. This report details preliminary findings of this test of accuracy.

Technical Description

The AT is a swing boom cable logging system. Other units similar to the AT are typically called jammer systems. The AT consists of three major components: a small dozer of 65 horsepower, a hydraulic knuckleboom loader, and a hydraulic winch. Operation is conducted with a single drum yarder to spool in the mainline and a pair of tongs (or chokers) to hook the logs. The tongsetter carries the mainline and tongs from the landing to the logs. Once the stem is yarded to the landing it is swung onto the road and the cycle is repeated (Fig. 1).

Economic Considerations

Total costs include all costs involved in buying, owning, and operating the logging equipment. Total cost is calculated as the sum of fixed cost, variable cost, and labor cost.

Annual fixed costs are calculated as the sum of annual charges for depreciation, interest, insurance, and taxes. Depreciation is calculated by the straight line method assuming a machine life of five years. The mathematical formula for straight line depreciation is:

$$D = \frac{P-S}{N} \tag{1}$$

where: D = yearly depreciation charge
P = Initial Investment cost of equipment
S = Salvage Value (20% of P)
N = Economic life in years.

Interest, insurance, and taxes are based on the average value of the yearly investment (AVI).

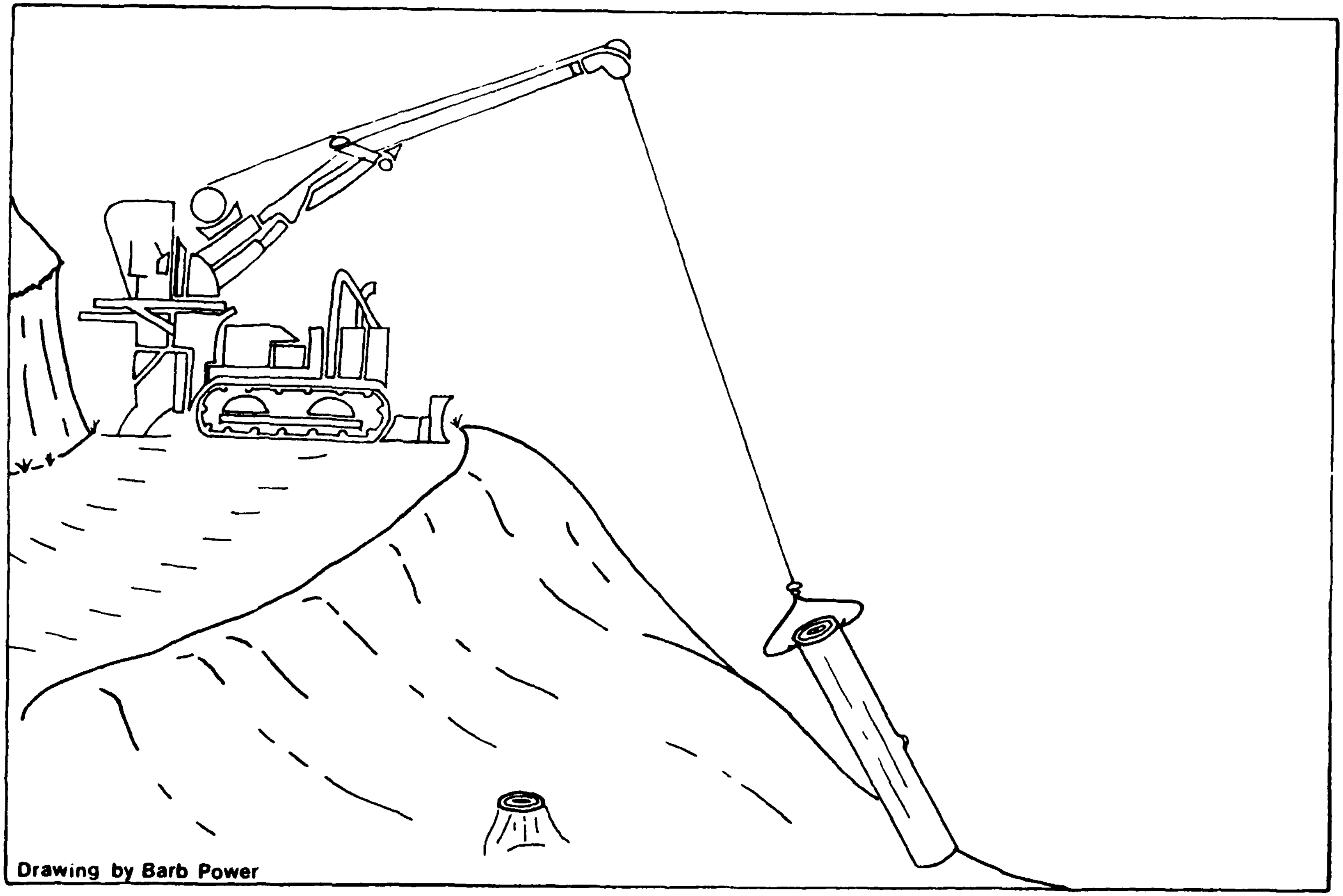

Figure - 1. Typical set-up of the Appalachian Thinner.

$$AVI = \frac{(P-S)(N+1)}{2N} + S \qquad (2)$$

Interest is calculated as 15% of AVI, Insurance as 3% of AVI, and taxes as 3% of AVI. Table 1 presents the calculations of total fixed cost for the Appalachian Thinner.

Table 1. Total Annual Fixed Cost of the Appalachian Thinner

	Initial Invst.	Salvage Value	Depr.	AVI	Interest (15% of AVI)	Ins. (3% of AVI)	Taxes (3% of AVI)	Total
	Dollars							
Tractor	36,417	7,283	5,827	24,764	3,715	743	743	11,028
Yarder	20,000	4,000	3,200	13,600	2,040	408	408	6,056
Total	56,417	11,283	9,027	38,364	5,755	1151	1151	17,084

Variable costs, unlike fixed cost, change in proportion to the total number of hours of operation. Variable costs include all cost of fuel, oil, lubricants, maintenance and repairs, and the total labor cost of a five-man crew (Table 2).

Table 2. Variable cost of the Appalachian Thinner

	Fuel	Oil & Lubricants	Cable Replacement	Maintenance & Repairs	Total
	Dollars per hour				
Tractor	1.788	0.127	---	2.882	4.80
Yarder	---	0.07	0.027	1.11	1.45
Labor (5 men @ 5.00/hour)					25.00
				Total variable cost	31.25

Source: Biller and Peters, 1981

Total revenue per day is based on the average volume harvested per day times the average value per Mbf of the logs at the woods landing. Board feet production per day is highly dependent on site factors thus it is evaluated according to the production capabilities of the yarder under specific logging conditions. Seven steps are necessary in order to predict daily production.

Step 1 - Board feet per setting

A "setting" is defined as the area of land that can be logged by the Appalachian Thinner in moving uninterruptedly along the harvest road. Harvestable board feet per setting is then a function of average maximum slope yarding distance, horizontal road movement, average board feet per acre, and the percent of stocking to be removed. Thus, harvestable board feet per setting is:

$$X_5 = ((X_1)(X_2)/43,560)\ (X_3)(X_4) \tag{3}$$

where: X_5 = Harvestable board feet per setting
X_1 = Average maximum slope yarding distance
X_2 = Appalachian thinner's horizontal road movement
X_3 = Stocking per acre in Mbf
X_4 = Percent stocking to be removed (decimal)

Step 2 - Yarding cycles per setting

The number of cycles necessary to harvest the entire setting is predicted by dividing the harvestable board feet per setting (3) by an estimate of the average board feet per cycle.

$$X_7 = X_5/X_6 \tag{4}$$

where: X_7 = Number of cycles per setting
X_5 = Harvestable board feet per setting
X_6 = Board feet per cycle

Step 3 - Hours required to harvest one setting

The hours required to harvest one setting is based on the number of cycles per setting (4) and the average number of minutes per complete cycle.

$$X_9 = \frac{(X_7)(X_8)}{60} \tag{5}$$

where: X_9 = Hours required to harvest one setting
X_7 = Number of cycles per setting
X_8 = Minutes per cycle

Cycle time is a function of average slope yarding distance (SDist), type of a harvesting operation, and the average number of logs per turn (Nlogs). The linear regression equations derived from production data (Biller and Peters, 1981) were used for cycle time estimates as follows:

Clearcut Cycle Time (add 1.81 minutes/cycle delay time)
Cycle Time = .1829 + .0185 (SDist) + 1.6429 (Nlogs)
R^2 =.62

Diameter Limit Thinning Cycle Time (add 1.40 minutes/cycle delay time)

Cycle Time = .5665 + .0124 (SDist) + 1.5800 (Nlogs)
R^2 = .41

Step 4 - Number of settings per tract.

The total number of settings on the tract is predicted by dividing the total tract area by the estimated area of a harvest setting.

$$X_{12} = X_{10}/X_{11} \tag{6}$$

where: X_{12} = Total number of settings per tract
X_{10} = Tract size (acres)
X_{11} = Setting size (acres)

Step 5 - Total time required to harvest the tract

The total time required to harvest the tract is a function of the hours required to harvest one setting (5), the number of settings on the tract (6), the moving time, and entry and exit time.

$$X_{15} = \frac{(X_{12})(X_9) + (X_{12})(X_{13}) + X_{14}}{60} \tag{7}$$

where: X_{15} = Total time required to harvest the entire forest tract.
X_9 = Hours required to harvest one setting
X_{12} = Number of settings on the tract
X_{13} = Moving time (5 minutes)
X_{14} = Entry and exit time (1 hour)

Step 6 - Average time required to harvest one Mbf (hours)

The average time, in hours, to harvest one Mbf of timber is estimated by dividing the hours required to harvest the tract by the total amount of harvestable board feet.

$$X_{17} = X_{15}/X_{16} \tag{8}$$

where: X_{17} = Average time required to harvest one Mbf (hours)
X_{15} = Hours to harvest the tract
X_{16} = Total expected harvest (Mbf)

Step 7 - Average production per day (Mbf)

The average board feet production per day is predicted by multiplying the average time per thousand board feet of timber (X_{17}) by the number of productive hours in a day (7.0 hours based on test).

$$y = (X_{17})(7 \text{ hours}) \tag{9}$$

where: y = Average board feet production per day (Mbf)
X_{17} = Average time required to harvest one Mbf (hours)

Cost per Mbf

In order to estimate the average cost per Mbf, fixed cost is reduced to an hourly cost by assuming a total number of hours of production per year. For the purpose of this study, 1800 hours of production per year was assumed. Thus total hourly cost (THC) is:

$$\begin{aligned} THC &= FC/1800 + VC \\ &= 17084/1800 + 31.25 \\ &= 40.74 \end{aligned} \tag{10}$$

where: THC = Total hourly cost
FC = Annual fixed cost
VC = Variable cost per hour

and total cost per Mbf is derived by:

$$\text{Cost per Mbf} = THC(X_{17}) \tag{11}$$

Breakeven Analysis

Breakeven analysis was chosen because it incorporates all relevant factors into the prediction process. Total annual fixed cost, variable cost, and daily production are combined into an algebraic breakeven equation in order to predict the number of days required to breakeven. Through this analysis a logging operator can ascertain the potential profitability of logging with the AT under a given set of logging conditions.

$$DBE = \frac{FC/PPmbf - VCmbf}{DP} \tag{12}$$

where: DBE = Days required to breakeven
FC = Annual fixed cost
PPmbf = Average revenue per Mbf at the woods landing ($80.00)
VCmbf = Variable cost per Mbf (31.25 x X_{17})
DP = Average daily production (Y)

Economic Model

The following variables, including the algebraic breakeven equation, were included in a Fortran Watfiv computer program in order to allow predictions to be made under a wide variety of logging conditions.

- Type of logging operation
- Average number of logs per turn
- Horizontal road movement between settings
- Stocking per acre
- Percent stocking removed
- Average volume per cycle
- Cycle time regression equation
- Average and maximum slope yarding distance

- Number of acres in the tract
- Travel time
- Road building cost
- Profit and risk percent
- Variable cost per hour
- Total annual fixed cost
- Hours of production per year.

Figure 2 is a simplified flowchart of the Fortran computer program utilized to predict the number of days to breakeven, and average cost per Mbf of timber.

Accuracy of the Economic Model

In order to test the accuracy of the AT economic model, 20 logging areas of 1.0 - 2.0 acres each were selected. This portion of the study details the preliminary results of the accuracy of the economic model based on ten of these plots, all of them comprised of partial cuts. An additional ten clearcut plots are yet to be completed.

Ten plots ranging in size of 1.4 to 2.11 acres were selected for thinning operations. The tests were conducted on the Monongahela National Forest near Parsons, West Virginia. These 10 units underwent a 100 percent cruise yielding the following information:

- Exact size of area (acres)
- Stocking per acre (BFA)
- Percent of volume to be removed (VR)
- Average slope yarding distance (ASYD)
- Average maximum slope yarding distance (AMSYD)
- Estimated board feet per cycle (BFC)
- Estimated average number of logs per turn (Nlogs)
- Revenue per Mbf of timber at the woods landing (PMbf)

A summary of these variables for each of the ten thinning plots is shown in Table 3. Approximately 2 Mbf per acre was marked for removal. Ground slope of the ten units varied from 30 percent to 66 percent with a mean of 46 percent.

Table 3. Summary of data from ten thinned plots

Plot #	Acres	BFA	VR(%)	ASYD	AMSYD	BFC	Nlogs	PMbf
1	2.11	9,790	24	105	210	142	2.8	80
2	1.99	10,596	27	100	200	142	3.0	80
3	2.01	9,787	21	150	300	141	2.66	80
4	1.79	6,614	32	110	220	159	2.88	80
5	1.8	7,310	26	110	220	137	3.0	80
6	1.67	6,995	25	105	210	117	3.04	80
7	1.44	16,369	23	110	220	180	3.64	80
8	1.57	8,828	23	110	220	126	2.8	80
9	1.45	10,744	25	118	235	124	2.88	80
10	1.75	10,337	17	118	237	122	3.34	80

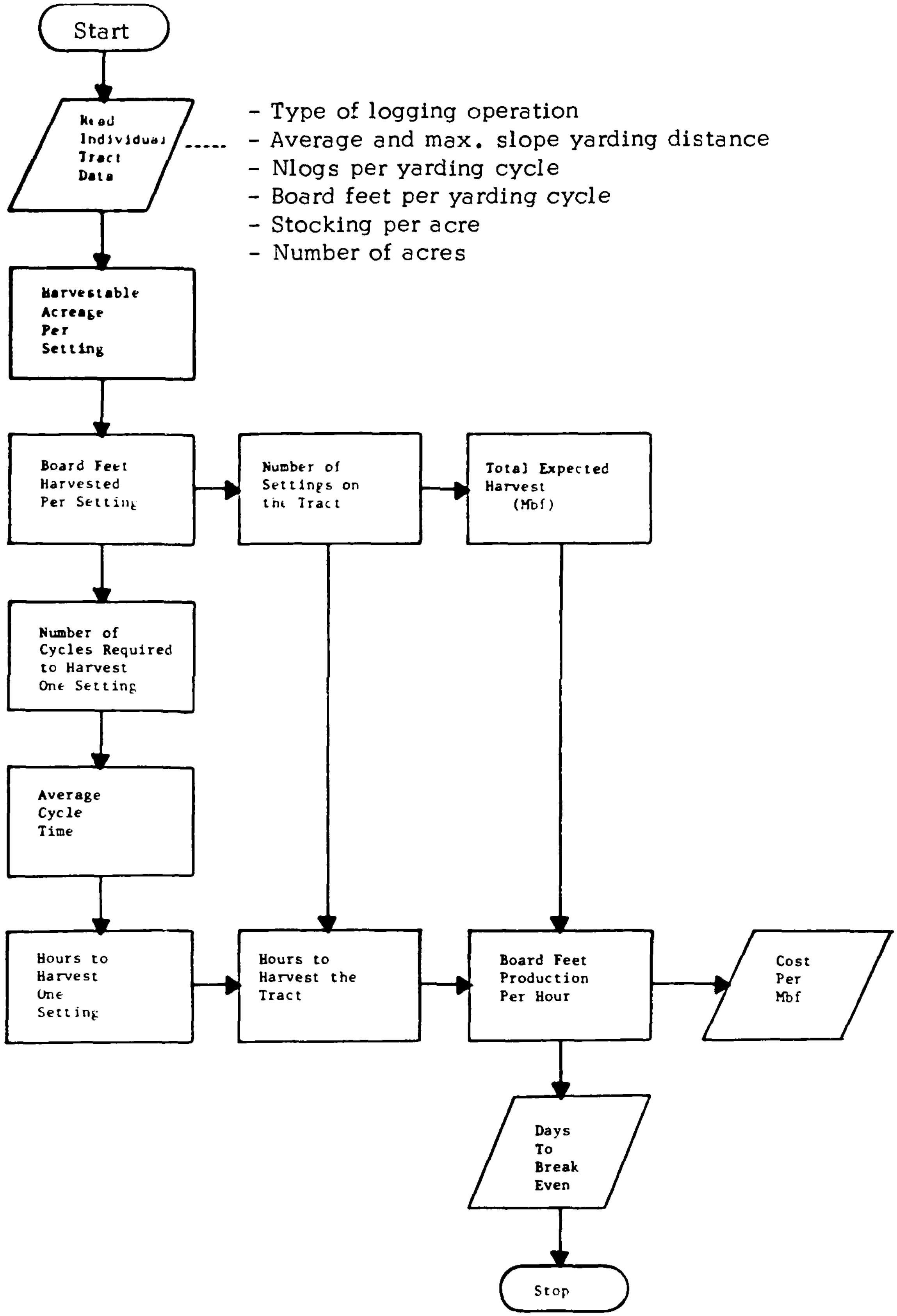

Figure 2. Flowchart of the Appalachian Thinner's Economic Model.

Based on cruise data and the estimated variable values shown in Table 3, the AT economic model was used to predict logging cost per Mbf and the average number of days required to break even. The average number of days required to breakeven for all of the ten thinning plots was 66.5 days and the average cost per Mbf was $50.59. A summary of predicted values for each of the ten thinning plots is shown in Table 4.

Table 4. Summary of cost and DBE predictions for ten thinned plots

Plot #	Total Vol. Harvested (BF)	Total Production Time (Hrs)	Production Per Hour (BF)	CPMBF*	DBE
1	4957	5.691	871	46.77	56
2	5693	6.54	870	47.39	57
3	4157	4.89	850	47.95	58
4	3739	4.00	935	43.59	49
5	3434	4.31	797	51.18	66
6	2872	4.22	681	59.85	92
7	5421	5.57	973	41.82	48
8	3216	4.172	771	52.85	70
9	3868	5.068	763	53.37	72
10	3075	4.614	666	61.12	97

* Cost per Mbf assumes 1800 hours of production per year, and $40.74/hour of total cost.

Actual Logging Cost Determination

Logging operations were carried out during the Fall of 1983. Detailed time and production records were kept so that actual cost per Mbf for logging each of the areas could be determined. Variable cost and fixed cost remained the same for actual and predicted values. Thus, if variation was to occur it could be attributed to the production of the AT under specific site conditions. Based on total time to harvest the tract and total board feet production of the tract, actual cost per Mbf and the number of days required to break even were derived (Table 5).

Table 5. Actual logging cost per Mbf and days to breakeven on ten thinned plots.

Plot #	Total BF Harvested	Total Hours of Production	BF Prod. Per Hour	CPMBF	DBE
1	5827	7.20	809	50.33	63
2	6205	6.68	929	43.85	50
3	4780	6.13	780	52.25	69
4	4070	4.74	859	47.45	57
5	3645	3.70	985	41.33	50
6	3345	5.031	665	61.27	97
7	5420	4.802	1129	36.10	36
8	3220	4.44	725	56.23	80
9	4264	5.80	735	55.43	78
10	2775	4.27	650	62.70	103

Comparison of Actual and Predicted Cost

The 10 cost and DBE prediction figures were compared with the 10 actual cost and DBE figures by means of a paired t-test analysis. The hypothesis was that the mean predicted cost per Mbf and DBE will not differ significantly (.10 level) from the mean actual cost per Mbf and DBE. This process provides the measure of accuracy of the model and indicates the usefulness of the model for profitability predictions.

Paired T-test Analysis

(1.) Hypothesis - mean predicted cost per Mbf will not differ significantly (.10 level) from the mean actual cost per Mbf.

Plot #	X_1 Predicted Cost/Mbf	X_2 Actual Cost/Mbf	D Difference $X_1 - X_2$
1	46.77	50.33	-3.56
2	47.39	43.85	3.54
3	47.95	52.25	-4.3
4	43.59	47.45	-3.86
5	51.18	41.33	9.85
6	59.85	61.27	-1.42
7	41.82	36.10	5.72
8	52.85	56.23	-3.38
9	53.37	55.43	-2.06
10	61.12	62.70	-1.58
	505.89	506.94	-1.58
	50.59	50.69	

where $t = \dfrac{\overline{X}_1 - \overline{X}_2}{\sqrt{sd^2/n}}$ and where: $sd^2 = \dfrac{\Sigma d^2 - (\Sigma d)^2/n}{n - 1}$

$$t = \frac{50.59 - 50.69}{\sqrt{23.18/10}}$$

$$sd^2 = \frac{208.52 - 1.1025/10}{10 - 1}$$

$$sd^2 = 23.18$$

t = -.06568
Critical "t" value, 9 degrees of Freedom, d = .10 = 1.833
Since .06568 < 1.833 Accept hypothesis.

(2.) Mean predicted number of days to breakeven will not differ significantly (.10 level) from the mean actual number of days to break even.

Plot #	X_1 Predicted #DBE	X_2 Actual # DBE	D Difference $X_1 - X_2$
1	56	63	-7
2	57	50	+7
3	58	69	-11
4	49	57	-8
5	66	45	21
6	92	97	-5
7	48	36	12
8	70	79	-9
9	72	78	-6
10	97	103	-6
	677	665	-12
	67.7	66.5	

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{sd^2/n}} \qquad \text{where } sd^2 = \frac{\Sigma d^2 - (\Sigma d)^2/n}{n - 1}$$

$$= \frac{1046 - 144/10}{10 - 1}$$

$$t = \frac{67.7 - 66.5}{\sqrt{114.622/10}}$$

$$= 1031.6/9$$

$$= 0.3544 \qquad = 114.622$$

Critical "t" *value, 9 degrees freedom,* d = .10 = 1.833
Since 0.3544 < 1.833 Accept hypothesis.

Based on the results of the paired t-test analysis the economic model is accurate in predicting logging cost at the .10 level. Predicted and actual logging costs do not differ significantly at the .10 level.

Summary and Conclusion

The accuracy of this economic model suggests that logging costs can be more precisely estimated if both site and production factors are considered when estimates are derived. A computer model that incorporates relevant site variables in the prediction process can be a helpful tool in making cost estimates.

Research is now underway to test the accuracy of the AT economic model in relation to clearcut logging operations. A greater understanding of the influence of site factors on cost will result in more efficient utilization of logging equipment and greater accuracy in predicting logging cost. The future of cable logging in the northeast lies in the adaptation of small cable yarders to steeply sloped woodlands where conventional logging is difficult, and accurate cost predictions will facilitate that adaptation.

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THE CLEARWATER YARDER: A MISSISSIPPI CASE STUDY

James R. Sherar
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SUMMARY

Production rates, production costs, and operating characteristics of the Clearwater Yarder were determined for a 3.31 acre clearcut in northeastern Mississippi. An average of 1.36 stems, containing 33.24 cubic feet were yarded per cycle. Average cycle time, including cycle delays but excluding road and landing changes, was 3.97 minutes. Estimated yarding cost for the yarder and four-man crew was $ 22.66 per unit.

Additional keywords: cable, skyline, logging, harvesting

INTRODUCTION

Conventional ground systems often cause unacceptable disturbance in the loessial and coastal plain soils of northeastern Mississippi. On the short steep slopes of this region it is important to select harvesting systems that minimize soil disturbance. Cable systems may have the potential of significantly reducing soil disturbance on these fragile sites.

In an effort to quantify the changes in streamflow characeristics caused by different harvesting systems, three adjacent watersheds (Figure 1) similar in size, topography, and stand characteristics were selected for the study area.

The study area, located on the Holly Springs National Forest about 13 miles northeast of Oxford, Mississippi, was uniquely suited because streamflow characteristics have been monitored since about 1957. Watershed I (Figure 1) was harvested by a small cable yarder, watershed II was left as an undisturbed control, and watershed III was harvested by a conventional rubber-tired skidder. The upland pine-hardwood stand on watershed I consisted of about 29 percent pine and 71 percent hardwood. There were about 117 trees per acre (5" to 29" dbh) having an average volume of 20 cubic feet. The hydrological data will be analyzed by personnel at the U.S. Forest Service's Hydrology Laboratory in Oxford, Mississippi, and reported later. This paper reports on the production rates, production costs, and operating characterisitcs of the Clearwater Yarder[2] operating on watershed I.

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[2]The use of trade, firm, or corporate names is for the information and convenience of the reader. Such use does not constitute an official evaluation, conclusion, recommendation, endorsement, or approval of any product or service to the exclusion of others which may be suitable.

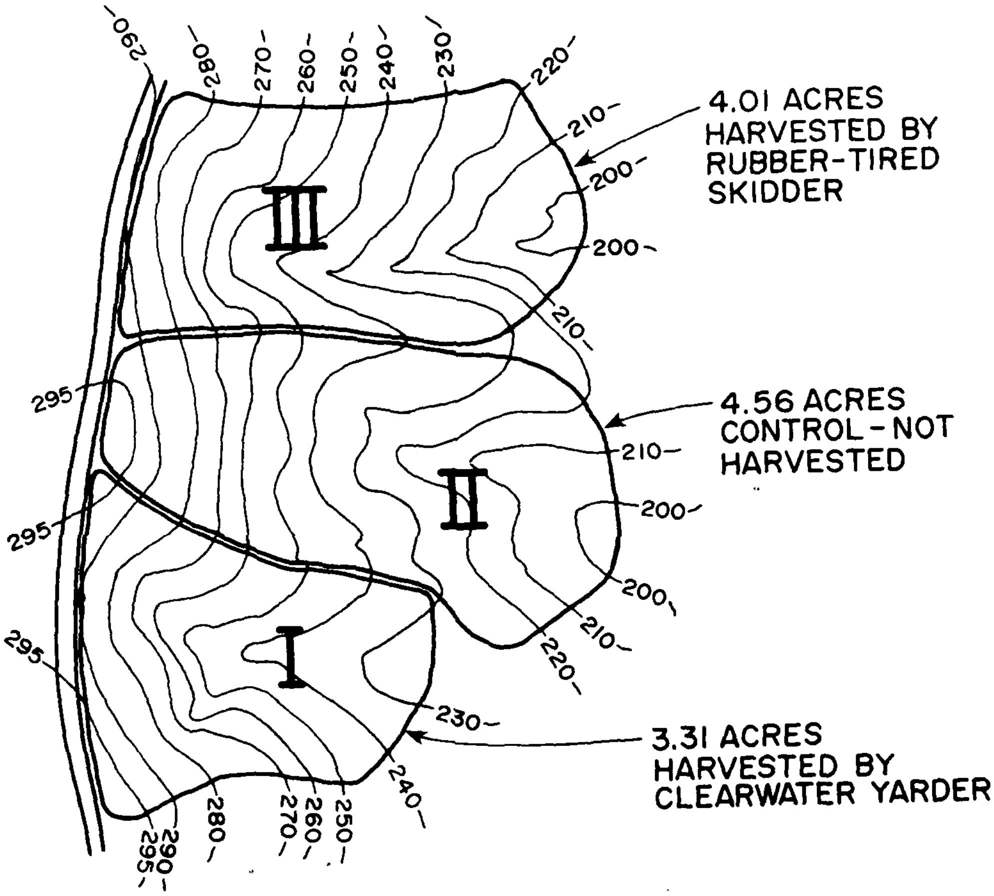

Figure 1. Upland pine-hardwood watersheds I, II, and III

METHODS AND MATERIALS

The Clearwater Yarder (Figure 2) was operated as a single-span skyline with a mini-Christy carriage. Although this yarder has haulback capabilities, the haulback drum was not functioning properly; therefore a gravity outhaul system was used. Equipment specifications for the yarder are given in Table 1 in the Appendix.

An experienced four-man, U.S. Forest Service crew consisting of a yarder operator, chaser, and two choker-setters were used. In addition, a Caterpillar 518 rubber-tired, cable skidder was used to winch some of the trees around the edge of the watershed and to skid the cable yarded logs one-fourth mile to the truck loading site. The cable roads, landings, and area harvested on watershed I by the rubber-tired skidder are shown in Figure 3. The unit had been prefelled and topped with the larger diameter trees cut into 14-foot log lengths, the remainder was yarded tree-length.

Crosby latching eye hooks attached to 8-foot midget chokers (Figure 4), were snapped onto 5-inch sliding rings on the mainline. If two or more stems were yarded per cycle, the mainline was first pulled to the stem located farthest from the skyline. One choker-setter would choke this stem and attach the hook to the bottom ring on the rigging. The second choker-setter would choke and attach the second stem to the mainline. Easy removal and attachment of the latching eye hooks to the rings allowed for presetting of chokers when time permitted.

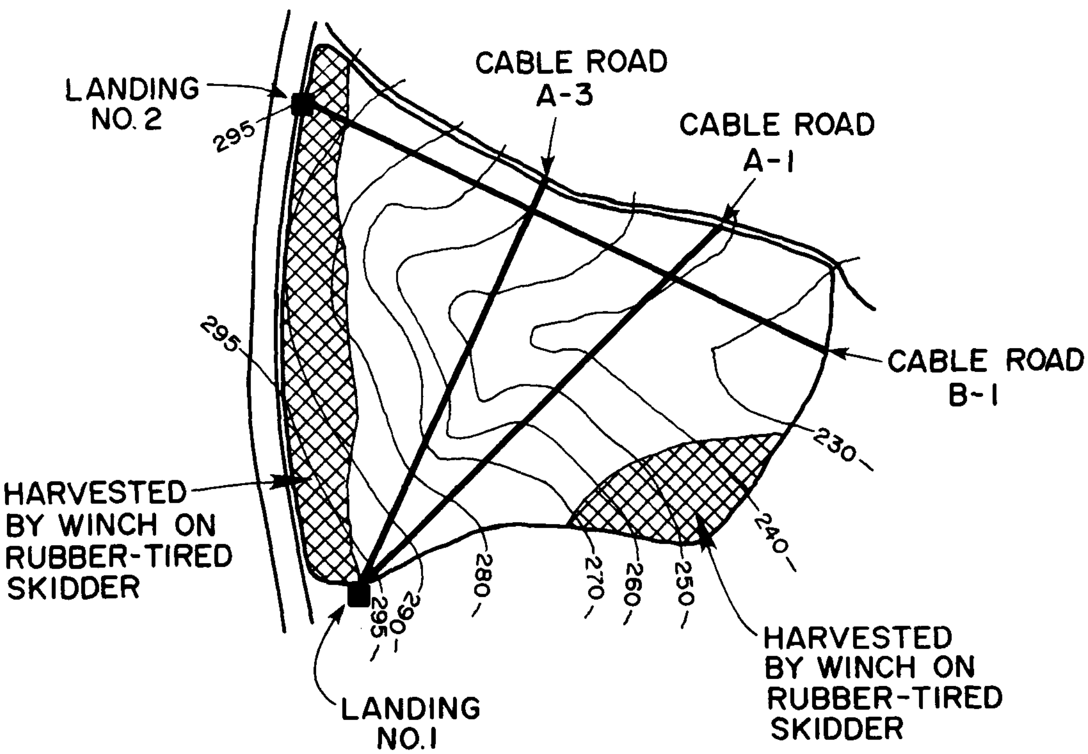

Figure 3. Harvest Pattern for Watershed I

Measuring Variables

The snapback method of timing was used to measure the elemental phases of each cycle. The following cycle elements (including delays) were measured to the nearest one-hundredth of a minute: 1) outhaul, 2) lateral outhaul, 3) hook, 4) lateral inhaul, 5) inhaul, and 6) unhook. The end diameters (inside bark) and length of all the yarded stems were measured. Smalian's formula was used to calculate cubic feet. Colored flagging tied at 100-feet-intervals along the cable road were used for ocular estimates of slope yarding distance (SYD). Lateral yarding distance (LYD) was also determined by ocular estimates. Cycles having one or more stems with a preset choker were also recorded.

RESULTS AND DISCUSSION

Production Rates

During 15 hours of scheduled harvesting time, which included road changes, landing changes, and delays, average hourly yarding production was 213 cubic feet (6.6 cycles; 9 stems). Based on the time study data, the average cycle time which includes cycle delays, but does not include the time required to change cable roads or the time to change landings, was 3.97 minutes. An average of 1.36 stems containing 33.24 cubic feet were yarded per cycle. The mean, standard deviation, range, and number of observations for selected yarding variables are given in Table I. The percent distributions of the cycle elements are shown in Figure 5.

Regression equations for the different cycle elements and total cycle time are shown in Table II. Slope yarding distance (SYD), number of logs per cycle (NLOGS), and cubic feet per cycle (FT3) were significant (alpha = 0.05) in either predicting the elemental time or cycle time.

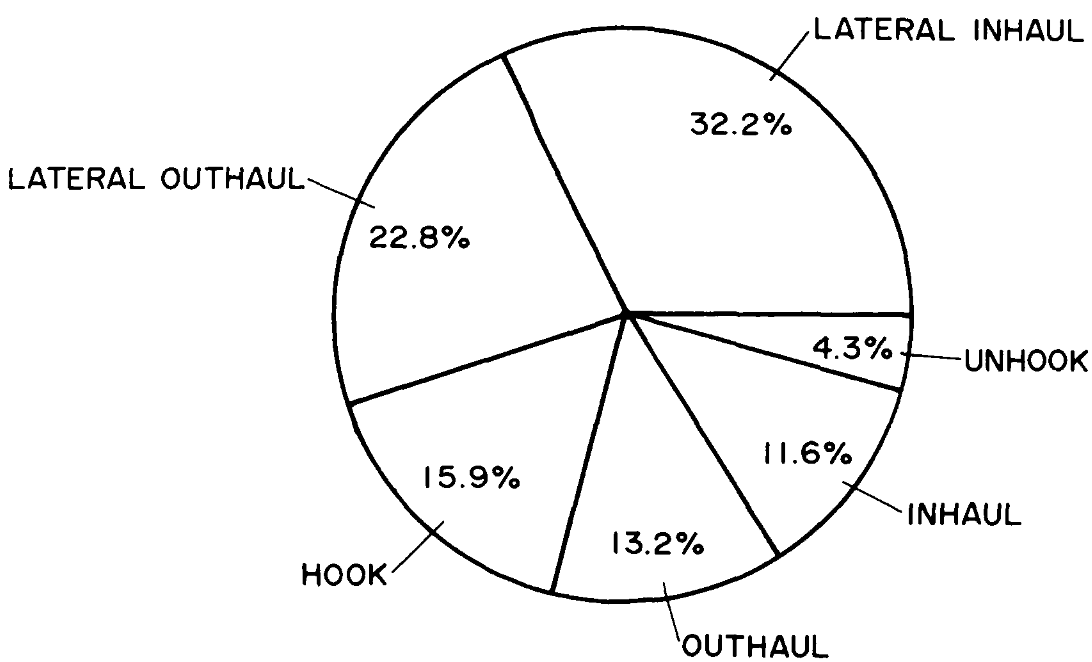

Figure 5. Percent Distribution of Cycle Elements

Table I. Characteristics of Selected Yarding Variables

Variable Description	Mean	Standard Deviation	Range	Number of Observ.
Cycle Elements, Including Delays (minutes)				
1. Outhaul	0.52	0.31	0.09 - 1.65	95
2. Lateral Outhaul	0.90	0.50	0.16 - 2.77	78
3. Hook *	0.63	0.95	0.02 - 8.18	78
a. chokers not preset	0.52	0.36	0.05 - 1.75	30
b. chokers preset	0.37	0.34	0.02 - 1.28	30
4. Lateral Inhaul	1.27	1.60	0.09 - 6.79	95
5. Inhaul	0.46	0.24	0.12 - 1.46	95
6. Unhook	0.17	0.13	0.04 - 0.79	95
7. Total Cycle **	3.97	1.93	1.57 - 10.29	95
a. chokers not preset	4.45	1.73	2.08 - 8.13	30
b. chokers preset	3.81	2.00	1.80 - 10.29	31
Cycle Volumes and Stem Characteristics				
1. Cubic feet (inside bark)	33.24	15.86	7.20 - 93.60	95
2. Number of stems	1.36	0.54	1 - 3	95
3. Stem Length (feet)	27.80	14.50	10.0 - 72.2	129
4. Large end diameter (inches)	15.10	3.50	8.4 - 28.8	129
5. Small end diameter (inches)	10.80	3.80	3.6 - 24.0	129
Cycle Yarding Distances (feet)				
1. Slope yarding distance	250	131	75 - 480	95
2. Lateral yarding distance	38	34	1 - 135	95

* Choker status was not obtained for the hook element on 18 cycles (78 - (30+30) = 18)

** Choker status was not obtained for total cycle time on 34 cycles (95 - (30+31) = 34)

Table II. Regression Equations Developed for the Clearwater Yarder

Yarding Phase	Regression Equation 3/	R-SQ	C.V.
Outhaul	Y = 0.14 + 0.0015(SYD)	0.38	48.02
Lateral Outhaul	Y = 0.42 + 0.0018(SYD)	0.27	48.19
Inhaul	Y = 0.23 + 0.00095(SYD)	0.27	44.22
Unhook	Y = 0.11(NOLGS) + 0.0014(FT3)	0.30	66.40
Total Cycle	Y = 2.00 + 0.002(SYD) + 0.36(NOLGS)	0.24	19.60

3/ Y = time in minutes
SYD = slope yarding distance in feet
NOLGS = number of logs per cycle
FT3 = cubic feet per cycle

Production Costs

In order to determine production costs, several assumptions were made concerning equipment efficiency, equipment life, and interest rates (Table 2). The method used to compute fixed and variable costs is similar to those described by Mifflin and Lysons (1978)and Miyata (1980). The estimated cost for the Clearwater Yarder and a four-man crew was $48.27 per scheduled hour. Based on the production rates for the 15 scheduled hours, the estimated yarding costs (stump to landing) were $22.66 per 100-cubic-feet (cunit) or $5.36 per stem. This does not include costs associated with moving in, the partial use of support equipment, felling and bucking, or a margin for profit and risk on the investment.

Discussion

In this study the hook element was 16 percent of total cycle time. Similar studies (Biller & Fisher 1982) show hook time as 30-40 percent of total cycle time. This reduction could be attributed to fewer stems yarded per cycle and the use of latching eye hooks and rings. Presetting chokers resulted in a 29 percent reduction in hook time and 14 percent reduction in cycle time. The reduction in cycle time was due to a lower hook time, and to the additional thought and planning given to turn size, log position, and lateral inhaul routes when chokers were preset.

Slope yarding distance (SYD) was the only variable significant in explaining the variation in outhaul, inhaul, and lateral outhaul times. This was apparently due to: 1) the relatively flat chord slopes (10%) which made manual slack-pulling very difficult, and 2) the increased weight of the mainline as slope yarding distance increased.

Due to the erosiveness of the soils in northeastern Mississippi, skyline yarding can be an alternative method for reducing disturbance caused by typical ground-based harvesting systems. Results from a study by Till (1980) indicate that the Clearwater Yarder does not cause enough soil disturbance to create erosion problems even on 40 to 80 percent slopes. Due to the relatively gentle terrain and flat chord slopes, skyline yarding production using gravity outhaul in this study was low. Although the Clearwater Yarder has haulback capabilities that would have increased production, the haulback drum was not functioning properly and was not used. Future skyline logging in this type terrain should feature haulback capabilities and machine slack-pulling. Yarding equipment with increased mainline drum pull is also needed in the size timber on this study area. The use of latching eye hooks and rings should be further studied with a yarder capable of hooking more stems per turn as a potential of significantly reducing hook time.

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APPENDIX

Table 1. Equipment Specifications for the Clearwater Yarder

Item	Description[4/]		
Developed and Built By:	Missoula Equipment Development Center USDA, Forest Service Missoula, Montana		
Currently Manufactured By:	Rolies Mill Supply Kalispell, Montana		
Mounted On:	Used tandem-axle truck		
Engine:	105 horsepower detroit diesel		
Tower:	10" by 10" by 1/2" wall square tubing,170 degree fairlead swivel hydraulically raised and lowered		
Transmission:	Hydrostatic		
Brakes:	Drum type, hydraulically operated		
Weight:	13,500 pounds (without tandem-axle truck)		
Drum Characteristics: (study conditions)	Skyline	Mainline	Haulback
capacity, feet	1000	2000	2000
line size, inches	9/16	3/8	3/8
line pull (max. pounds)	7500	3500	3500
line speed (feet/minute)	0-500	0-1000	0-1000
Rigging Configuration:	live skyline (uphill and downhill)		
1983 price estimate:	$92,400 (excluding used tandem-axle truck, but including wire)		

4/ Clearwater Yarder Operator's Manual (1981)

APPENDIX

Table 2. Operating costs for the Clearwater Yarder (1983 price estimates)

Item Description	Annual Cost	Scheduled Hourly Cost
Fixed Costs:		
Depreciation:		
Clearwater Yarder ($92,400 - $18,480)/8	$ 9,240.00	$ 5.78
Mini-Christy carriage ($4,600 - $920)/8	460.00	0.29
Used carrier truck ($15,000 - $1,500)/8	1,687.50	1.05
Taxes, Interest & Insurance (20% of AAI)	14,428.75	9.02
	$25,816.25	$16.14
Variable Costs:		
Maintenance & repair (50% x $11,387.50)	$ 5,693.75	$ 3.56
Fuel (yarder and truck)	3,460.00	2.16
Oil, grease, etc., (20% x $3,460.00)	692.00	0.43
Tire replacement (truck)	1,000.00	0.63
Tire repair (10% x $1,000.00)	100.00	0.06
Truck License & Fees	500.00	0.31
Wire Rope:		
Main ($0.45/ft x 1,000 ft x 0.50)	$ 225.00	$ 0.14
Haulback ($0.45/ft x 2,000 ft x 0.20)	180.00	0.11
Skyline ($0.62/ft x 1,000 ft x 0.50)	310.00	0.19
Guylines ($0.70/ft x 300 ft x 0.50)	105.00	0.07
Chokers ($15.00/choker x 50/year)	750.00	0.47
	$13,015.75	$ 8.13
Labor:		
(4 men x $6.00/hr x 1,600 hours/year)	$38,400.00	$24.00
	$77,232.00	$48.27

Assumptions: Years life = 8, Salvage rate = 20%, Scheduled hours = 1,600/year Operating hours = 1,200/year, Labor rate = $6.00 per scheduled hour and includes overhead, insurance, social security, etc.

PRODUCTION STUDY OF THE KOLLER K300 CABLE YARDER OPERATING IN THE MOUNTAINS OF VIRGINIA

William B. Stuart
Michael K. Rossie

ABSTRACT

A production and cost study for the Koller K300 skyline yarder operating on an Appalachian timber sale was undertaken to document the yarder's performance, to identify predictors of yarder performance, to evaluate the impact of corridor dimension on machine productivity, and to estimate direct harvesting costs.

Simulation analyses were used to investigate the effects of changing corridor dimension on average hourly yarding productivity in light of machine setup time. Corridor widths of 52 feet resulted in significantly less production than widths of either 104 or 208 feet when yarding road changes were assumed to require two hours. Corridor lengths of 208 feet were significantly less productive than lengths of 416 or 624 feet. No significant difference in productivity was found for the three corridor lengths when road changing time was reduced to one hour. Again, the 52 foot corridor widths were less productive.

Estimated direct harvesting costs (on board truck) are given for two system configurations and three utilization levels. The estimates range from $22.21 per cord to $37.14 per cord.

INTRODUCTION

A study was conducted during the summer of 1982 to evaluate the performance of a Koller K300 yarder in a clearcut harvest in the Pedlar Ranger District, George Washington National Forest in Amherst County Virginia. This study was supported by the U.S. Forest Service, Forest Engineering Laboratory, Morgantown, West Virginia, with the goal of documenting the performance of the yarder, identifying those variables which impacted on machine productivity, developing models for predicting performance on other sites, evaluating the impact of corridor and yarding distances on yarder productivity and estimating the total cost of harvesting with the yarder.

The Koller K300 Yarder

The Koller K300 yarder is manufactured in Kufstein, Austria by J. Koller and consists of a 23 foot (7 meter) tower and two-winch drum set. The unit may be mounted on a carrier equipped with a three-point hitch and driven by the carrier's power take-off (PTO) shaft or mounted on the Koller trailer with integral engine. The minimum driving output requirements for the yarder is 40 hp (30 kw).

Owens-Illinois' K300 yarder is a slight modification of the three-point hitch design (See Figure 1). The yarder is mounted on the rear of a refurbished Timberjack 230D skidder. The drum set is driven by a Sundstrand fixed-displacement hydraulic motor and variable-displacement pump. Power to the pump is supplied by a link to the crankshaft of the Timberjack's GMC 3-53 diesel engine.

Power transmission to the mainline and skyline winches is accomplished by individual hydraulically-assisted single plate dry clutches. Skyline tension is maintained by a manually operated overband brake. The mainline drum is braked by a hydraulically-assisted band.

The mainline drum has a spool capacity of 1150 feet (350 meters) of 3/8 inch (9.5 mm) wire rope and develops an average line pull of 3950 pounds (1790 dN). Line speed varies from 0 to 16 feet per second (5 meters per second) depending on the input shaft speed. The skyline drum has a spool capacity of 1150 feet (350 meters) of 5/8 inch (16 mm) wire rope. The skyline is tensioned on a section of bare drum adjacent to the storage drum. The average line pull in this section is 9920 pounds (4500 dN). The yarder is equipped with two 100 foot (30 meter) wire rope guylines spooled on manually operated winches. The guyline diameter is 9/16 inch (15mm).

The system employs a Koller self-clamping carriage (Model SKA 1) with multispan capabilities. The carriage weighs 330 pounds (150 kg) and has a load capacity of 1.1 tons (1 metric tonne). A skyline slope of at least 15 percent is required for effective gravity outhaul.

Two clamping mechanisms are contained within the carriage and activated by hydraulic pressure derived from a sheave-driven pump and accumulator. The first clamping device controls the carriage brake on the skyline while the second device controls the cams which hold and release the yarding hook attached to the end of the mainline. The self-clamping design permits remote operation of the carriage by the yarder operator.

The Timber Stand

The stand upon which the machine was evaluated was an upland hardwood site the predominant species being chesnut oak approximately 80 years old. Average stand diameter was in the 10 to 12 inch class and volume per acre was approximately 2000 cubic feet of sawlogs and pulpwood. Slope on the site ranged between 20 and 40% over a rocky soil. The machine was evaluated on three corridors, two of which were concave, crossing a small creek near the tail hold. The third was a continuous slope.

Figure 1: The Owens-Illinois yarder

Machine set up varied at each of the corridors. On Corridor One it was rigged with an intermediate support 50 feet from the tower at the brow of the hill to allow the operator to take advantage of a large decking area. Logs were landed directly under the mainline and bucked if necessary by one of the landing crew and loaded directly to straight frame trucks for transport from the site. At Corridor Two the machine had to be set up on a permanent road to achieve the desired amount of lateral yarding access. This set up allowed no room for the landing and a Cat 518 skidder was used to swing the logs from the yarder to the loading area. In Corridor Three the machine was set up without intermediate supports on the brow of the hill. Only enough landing space under the tower was available to accumulate 2 yarder turns for the swing skidder. The skyline span in all three setups was between 400 and 460 feet.

The yarding crew consisted of 6 men. One feller, two choker setters, an operator-foreman, and 2 truck drivers. A system supervisor divided his time between this crew and a second company logging operation. All crew members were between the ages of 26 and 44 and had at least 8 years of logging experience and 5 years of experience with the company. Although their total formal education in skyline yarding had been a one day workshop conducted by the equipment salesman at the time the yarder was purchased, all crew members had had more than one year's experience with the machine in a similar operating environment.

Data Collection

The data collection for the project occurred over a 60 day period from late July 1982 through late September. The study was interrupted several times because of changes in crew allocation, machine breakdowns, alterations in study plans and weather conditions affected continuity. One acre mapped stands were established on Corridors One and Two to define the stand characteristics prior to cutting on these corridors. Time and staffing did not permit the mapping of the stand on Corridor Three. Throughout the study continuous timing was used to document element, cycle and delay times to the nearest one hundreth of a minute. Whenever possible the operation was also video taped to supplement field data. The video taping approach was found to be particularly useful in identifying delay causes and to refine elemental times from the stop watch data.

Seven elements were chosen for inclusion in the time study:

1. Outhaul - the time required for the empty carriage to travel from the deck to the carriage stop on the skyline.

2. Mainline drop - the time required for the yarding hook to reach the ground after outhaul.

3. Walkout and set chokers - the time required to secure a turn to the mainline.

4. Winch slack - the time required to winch in mainline slack before winching the turn laterally.

5. Winch laterally - the time required for the turn to be winched from its bed to the yarding hook lock in the carriage.

6. Inhaul - the time required to winch the turn uphill to the landing.

7. Unhook - the time required to unhook the chokers at the landing.

In addition, the yarding distance from the tower to the carriage lock and lateral yarding distance, the horizontal distance from the carriage lock and farthest log hooked in the turn were recorded for each turn. When a turn was dropped on the landing, the large and small end diameter and total length of each piece were measured to allow computation of cubic foot volume by Smalian's formula. In all 216 total cycles were timed using stop watch methods. An additional 5½ hours of yarding activity was video taped.

In summary, statistics for productive time are given in Table 1 and delays observed are shown in Table 2.

Step wise regression analysis was used to attempt to relate total cycle time and elemental times to various factors of the environment. The results of these analyses are shown in Table 3. The total time equation was developed for each of the three corridors studied and a test for coincidence and parallelism was used to determine if the different corridor characteristics had any effect on the prediction of total cycle time. The results of this analysis indicated that there were no significant differences between the corridors from the effects of yarding distance, lateral distance, or any factors which may be hidden in the intercept of the regression. Although the predictability of this model is rather low (P = .39) the residuals tend to be distributed rather uniformally around the line as shown in Figure 2.

Lateral yarding was found to be affected by lateral distance, slope distance, and number of pieces. These three variables combined account for less than one quarter of the variation in the observed times. The element was broken down into two sub-elements, lock and set chokers and lateral winching time. The best model for each of these two elements, when considered independently, was found to contain only the lateral distance. The affect of slope distance and number of pieces dropped out of the analyses. A test for coincidence in parallelism across all three corridors for lateral yarding indicated that only a slope distance had an affect which varied between corridors. The impact of this variable was relatively small and its presence in the model difficult to rationalize.

Inhaul distance proved to be the most predictable of all machine elements. It was found to be affected only by slope distance. This allows drawing two inferences from the study. First that machine operation was quite consistent and secondly that variable loading of the carriage had little impact on this component of cycle time. Consequently, the best productivity can be achieved when machine loading approaches capacity. Tests for coincidence in parallelism across corridors found that the time for Corridor Three was significantly different from that for Corridors One and Two. The skyline on this corridor was rigged as a low single span with relatively little deflection and many of the logs plowed into the ground as they were skidded uphill. The resulting resistance effectively slowed the inhaul rate.

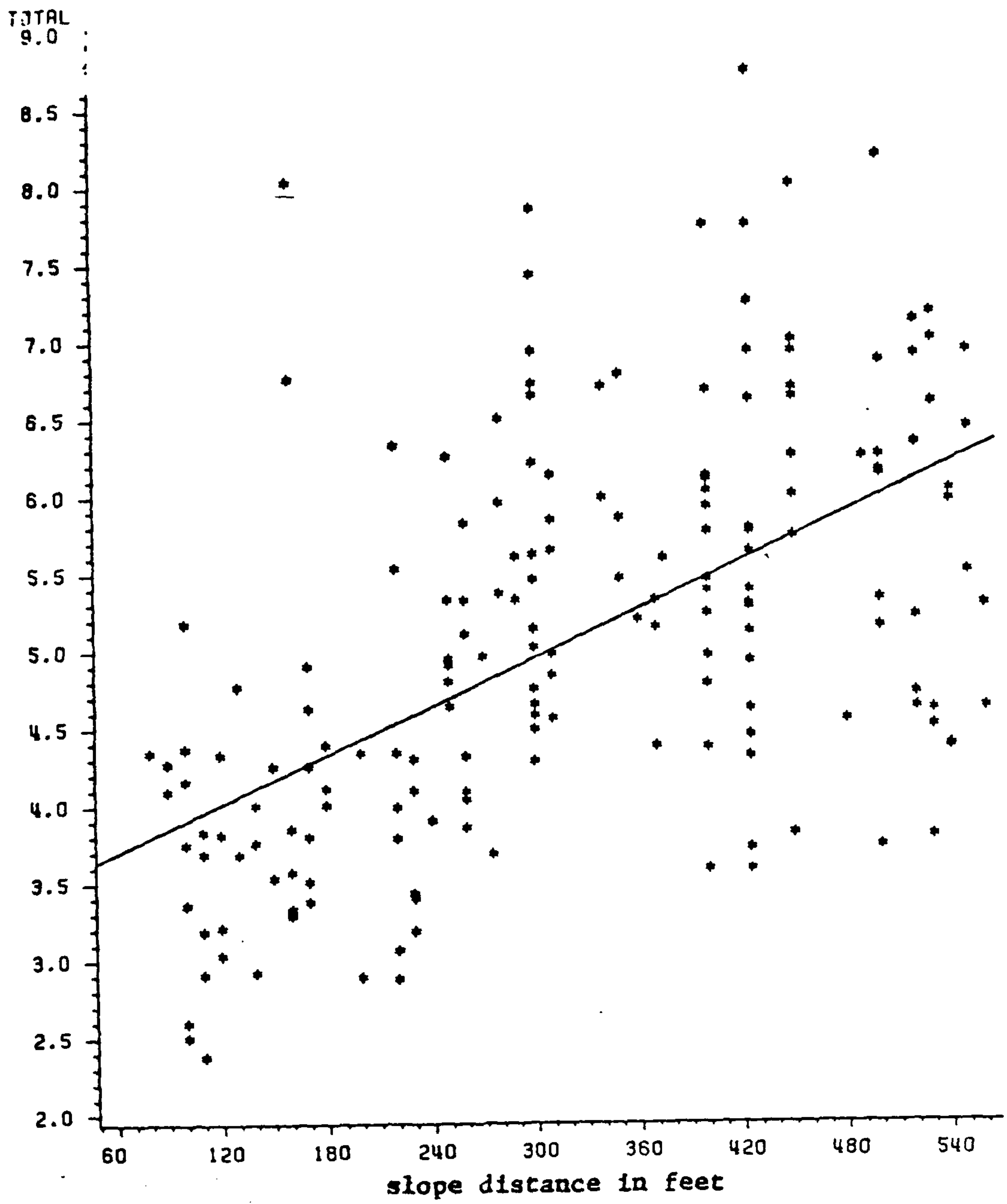

Figure 2 : The effect of slope distance on total cycle time

Table 1: Summary Statistics - Productive Time

	Mean	Std. Dev.
Yarding Distance - Feet	328	137
Lateral Distance - Feet	45	35
Number of Pieces/Turn	1.64	0.63
Volume/Turn - Cubic Feet	36.07	17.69
Elemental Times - Minutes/Turn		
Outhaul	0.49	0.15
Lateral yarding including hook	2.92	1.06
Inhaul	1.18	0.49
Unhook	0.56	0.33
Total Cycle	5.10	1.30

Table 2: Operating Delays

Delay Description	Average Duration (Minutes)	Frequency of occurrence (per 100 cycles)
Lateral Yarding Delays		
Load won't breakout	2.39	13.9
Chokers required adjustment	6.00	1.0
Chokers or mainline tangled	1.84	1.0
Operator away from controls	1.07	0.5
Inhaul Delays		
Inhaul grounded	4.83	2.3
Unhook Delays		
Mainline tangled at landing	0.64	1.0
Total Cycle Delays		
Mainline break	27.34	2.3
Miscellaneous	19.74	1.4

Table 3

Predictive Models for Total and Elemental Productive Times Per Cycle

1) Total cycle time (minutes) = 2.925 + o.005 (slope distance) + 0.0114 (lateral distance)

$R^2 = 0.388$

2) Lateral yarding time (minutes) = 1.627 + 0.0126 (lateral distance) + 0.0010 (slope distance) + 0.2116 (number of pieces)

$R^2 = 0.224$

3) Walk and Set Chokers (minutes) = 1.181 + 0.0187 (lateral distance)

$R^2 = 0.325$

4) Lateral winching time (minutes) = 0.361 + 0.0046 (lateral distance)

$R^2 = 0.310$

5) Inhaul (minutes) = 0.260 + 0.0028 (slope distance)

$R^2 = 0.638$

6) Outhaul (minutes) = 0.216 + 0.0008 (slope distance)

$R^2 = 0.556$

7) Unhook

Corridor	Mean	Std. Dev.
1	0.50	0.23
2	0.72	0.50
3	0.49	0.21

Table 4

Average Hourly Cubic Foot Volume Production with Two Hours Road Change Time

CORRIDOR WIDTH

CORRIDOR LENGTH

	52'	104'	208'
208'	230.72 564.68 23 B	310.16 500.43 11 AB	383.86 488.30 5 A
416'	312.85 507.48 11 AB	363.50 455.83 5 A	406.38 446.85 2 A
624'	338.97 460.84 7 A	366.99 418.32 3 A	393.59 411.65 1 A

Average Hourly Cubic Foot Volume Production with One Hour Road Change Time

CORRIDOR WIDTH

CORRIDOR LENGTH

	52'	104'	208'
208'	326.15 564.68 23 B	386.56 500.43 11 AB	431.38 488.30 5 A
416'	388.77 507.48 11 AB	406.11 455.83 5 AB	426.37 446.85 2 A
624'	393.10 460.84 7 AB	395.57 418.32 3 AB	403.27 411.65 1 A

Blocks Containing same Letter are not significantly different at 95% level.

Outhaul time proved to be the next most predictable element with a predictability of approximately 56%. Outhaul is strictly a function of slope distance and coincidence and parallelism testing across corridors showed no significant difference in the model for any of the corridors observed.

Unhook time was found to vary between corridors because of differences in landing layout at each of the three locations. Only Corridor Two, where there was essentially no place under the tower for landing material for the swing skidder, was found to be significantly different, with an unhook time approximately 150% of that for the other corridors.

Simulation Studies

The parameters in the field studies were used in the GENMAC Machine Simulator program to model the effects of different combinations of corridor width and corridor length on machine productivity. Corridor lengths considered were 208, 416 and 624 feet. Corridor widths were 52, 104, and 208 feet. The results of the analysis are shown in Table 4. The first number within each block represents the hourly productivity considering road change time of two hours. The second number is productivity ignoring road change time and the third number represents the number of road changes required. Each combination was modeled cutting the same number of acres. Results of this analysis indicated that there was no significant difference between the expected productivity on the 400 and 600 foot corridor lengths. The 200 foot corridor length was significantly less productive. The 52 foot corridor width was also significantly less productive than the 100 and 200 foot widths. The table demonstrates that the number of road changes has a very important affect on yarder productivity and if the corridors are short, the lateral yarding distance should be kept as long as possible to reduce the impact of road changes. Wider corridors have relatively little affect as road change time decreases and corridor lengths extend beyond 400 feet.

Economic Analyses

Estimates of the on-board truck harvesting costs are given both with and without the inclusion of Catapiller 518 swing skidder in Tables 5 and 6. These projections are based on the direct cost incurred by a private logging contractor. Those costs not attributable to harvesting were not considered. The equipment was considered to be financed on a 20% down payment with 9% add on interest charges. Property taxes are calculated on the undepreciated life of the machine. Labor costs were figured using a base rate of $6 per hour plus 30% for fringes, and the contractors assumed the service of owner/skidder operator at a weekly salary of $270 dollars.

The chainsaw felling and topping teams were considered to have a 50% average utilization. The Koller was evaluated at 50, 60 and 70% utilization and the loader times were those necessary to accomodate the various levels of productivity from the yarder.

Costs were found to run approximately $25 a cord for felling, skidding and loading if the swing skidder was not required. Costs increases to approximately $32.50 per cord if the swing skidder was needed in the system.

Table 5: Estimated Felling, Yarding, and Loading Costs Assuming No Swing Skidder Necessary

	50%	60%	70%
Fixed Costs			
Koller	$251.42	$251.42	$251.42
Printice	$314.28	$314.28	$315.28
Saws (2)	$40.00	$40.00	$40.00
Labor Costs	$1599.00	$1599.00	$1599.00
Operating Costs			
Koller	$240.00	$288.00	$336.00
Prentice	$240.00	$288.00	$336.00
Saws	$60.00	$60.00	$60.00
Total Weekly Cost	$2744.70	$2840.70	$2936.70
Total cord Production	94.4	113.3	132.2
Total Cost/Cord	$29.07	$25.07	$22.21

*Saws have 50 percent utilization

Table 6: Estimated Weekly Felling, Yarding, and Loading Costs Assuming a Swing Skidder is Necessary

	50%	60%	70%
Fixed Costs			
Koller	$251.42	$251.42	$251.42
Prentice	$314.28	$314.28	$314.28
Cat	$454.76	$454.76	$454.76
Saws (2)	$40.00	$40.00	$40.00
Labor Costs	$1599.00	$1599.00	$1599.00
Operating Costs			
Koller	$240.00	$288.00	$336.00
Prentice	$240.00	$288.00	$336.00
Cat	$307.20	$307.20	$307.20
Saws	$60.00	$60.00	$60.00
Total Weekly Cost	$3506.66	$3664.10	$3821.54
Weekly cord Production	94.4	113.3	132.2
Total Cost/Cord	$37.14	$32.34	$28.91

*Saws have 50 percent utilization

Achieving these costs is dependent upon maintaining at least a 60% utilization level on the yarder, and maintaining productivity rates similar to those observed during the field studies.

Fixed costs and labor account for nearly 80% of the total weekly costs for the system. Consequently any change in utilization or productivity can have a very dramatic affect on per unit costs. This in fact has proven to be the case with the yarder observed during this study. Difficulty in maintaining machine availability and utilization coupled with operational time lost due to road conditions and site conditions resulted in production costs considerably higher than those reported here. The yarder has since been retired from production and is currently for sale.

Cable yarding can be an efficient and environmentally sound means of removing commercial material from steep slopes on sensitive soils in Appalachia. Mechanical characteristics of the machines required have been developed and tested in various portions of the world. The low volume and values per acre in much of the Appalachian region coupled with the necessity for maintaining relatively high availability and utilization rates to compensate for the fixed costs of cable yarding systems have tended to restrict the acceptance of these systems across much of the area.

FUNCTIONAL REQUIREMENTS AND DESIGN PARAMETERS OF SWING-TO-BUNCH FELLER-BUNCHERS FOR FOREST THINNING

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ABSTRACT

Interactive simulation is used to obtain data relating design parameters to functional requirements of swing-to-bunch feller-bunchers. Design parameters include reach ratio, operating rates, boom/machine weight ratio and boom support locations. Functional requirements include thinning selectivity productivity, tipover stability, bunching capability, structural integrity and boom-tip control.

A hierarchical, level-of-detail based procedure is described and used to develop functional requirement and design parameter relationships from the data generated by interactive simulation.

The results indicate that the proposed procedure is suitable for determining design parameters to meet specific functional requirements in the design of swing-to-bunch equipment. Examples of steep-slope and plantation thinning designs are included and the trade-offs in requirements with respect to the design parameters are discussed.

INTRODUCTION

Thinning is a silvicultural treatment performed to alter the distribution of forest stand characteristics by removing selected trees. Cutting can be accomplished mechanically with swing-to-bunch feller-bunchers which address the trees individually by reaching with a boom or arm. Both productivity and success in obtaining the desired characteristics in the thinned stand depend on the design of the feller-buncher.

Design of any machine or machine system is a decision making process in which certain parameters (design parameters) are

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specified in order to meet operational requirements and constraints (functional requirements) which describe the objective of the design. The specification of a machine to cut and bunch trees for thinning forests is an example of a large complex design problem. Conceivably, an optimal solution to the problem could be found. Realistically however, optimization of the thinning system is not currently possible because complete descriptions of the relationships between the many design parameters and the functional requirements do not exist.

This paper addresses the design of swing-to-bunch feller bunchers, for thinning forests, in terms of design parameters and functional requirements.

OBJECTIVE

The objective is to apply principles of systematic engineering design to concept development of feller-bunchers. The approach includes developing a hierarchical, level-of-detail based procedure for design.

DESIGN PARAMETERS AND FUNCTIONAL REQUIREMENTS

The concept of a systemetized design process is frequently discussed in engineering textbooks, articles, and research papers. While some may believe that attempts to design through structured procedures restricts creativity, others such as Suh (1978) believe that a systematic approach will lead to better (nearer optimal) designs. Computer Aided Design (CAD), in a broader sense than just computer aided drafting, requires a systematic well organized approach.

As a decision making process design is poorly understood, thus it is often considered largely an artform. The decision making process consists of specifying values for certain parameters (Design Parameters or DPs) which can be directly controlled by the designer. Geometric dimensions are usually DPs. Requirements of, or constraints on, a design are Functional Requirements or FRs. Geometric dimensions can also be FRs but a more typical example would be the throughput or productivity of a machine. The essence of good design is then the selection of the appropriate values of the Design Parameters (DPs) to meet a set of particular Functional Requirements (FRs). An ambiguity typically arises because a specific (limited) set of DPs must satisify a wide range of FRs. Forest harvest equipment design is an example of a case where the range of the FRs is often very wide.

The specification of a simple pair of gears is an example of a well defined design problem. The design of a gear set to to provide an output shaft speed of one half that of the input shaft illustrates the DP/FR concept. The shaft speed ratio of one half is a functional requirement. The design parameter which can be adjusted to meet the speed ratio requirement is the ratio of the number of teeth on each gear. Additional functional requirements must be used as basis for selecting values for other DPs. Torque, allowable size, minimum efficiency, and actual speed are potential FRs which may be used in specifying DPs such as gear diameters, width, cut, and material. In the gear design example the FRs and DPs are related via specific (deterministic) equations. However, in other design problems the relationships may be determined through experimentation (e.g. time studies) or computer modeling (e.g. simulation).

Lacking any systematic structure, design would be a monte-carlo experiment consisting of trying various combinations of values for the DPs. In reality a procedure of setting and adjusting DPs to "improve" the design is always done (if only in the designers head). DPs and FRs might never be explicitly stated when specifications are made via a procedure which exists only in the individuals thought process. Systemitized design however, requires (and will in part consist of) explicitly identifying DPs, FRs, and the relationships between them. The relationships may be in the form of physical laws and equations, tables of data, or individual data points which can be generated through experimentation or computer simulation, and provide the mapping between the design and the performance of the design. Additionally, a procedure must reflect the relative importance of FRs and the DPs which are specified to satisfy the various DPs.

A set of axioms for design has been proposed by Suh (1978 and 1979). In reference to manufacturing systems, Suh sugests that "there exists a small set of global principles, or axioms, which can be applied to decisions made throughout the synthesis of a manufacturing system. These axioms constitute guidelines or decision rules which lead to 'correct' decisions, i.e., those which maximize the productivity of the total manufacturing system, in all cases." The seven original proposed axioms were combined into two design and manufacturing axioms by Rinderle (et.al. 1982);
axiom 1 "maintain the independence of functional requirements"
axiom 2 "minimize the information content".
The axioms suggest that a design process should be organized so that the functional requirements can be met individually such as by changing only one design parameter to meet each one of the functional requirements. The axioms also imply that designs and design procedures be as simple as possible while satisfying the FRs.

Systematic approaches to design have been attempted. A design spiral is used by Calkins (1983) as a basis for structuring the computer aided design of recreational power boats. The design spiral represents an iterative design process in which various aspects of the design (e.g. hull, engine, and propeller) are addressed repeatedly and in increasing detail as the process proceeds. The design spiral is a level-of-detail based design process in which the most important functional requirements are satisfied early. Specifying the DPs which determine FRs related to the ability of a machine or system to accomplish the intended task is essential to good design.

FELLER-BUNCHER DESIGN

Feller-bunchers for forest thinning can be examined in terms of Functional Requirements and Design Parameters. Boyd and Novak (1977) described the distinction between "concept" and "performance" in forest harvesting equipment. "Performance" represents the ability of a machine or system to execute the required tasks. "Concept" refers to the machine functions executed and the overall arrangement of components and system geometry. Performance is determined by concept and the detailed design of the machine system. Successful concept development and design is dependent on understanding how the FRs and DPs are related.

Geometric Modeling (Fridley and Jorgensen, 1983) and Interactive Simulation (Fridley, Jorgensen, and Garbini, 1982) are two methods for relating (or mapping) the FRs to the DPs. Geometric modeling predicts the machine's capabilities for selective thinning on the basis of working envelope geometry and average stand density. Interactive simulation consists of determining a complete description of an operating path (including motions of the prime-mover and the boom) which may be followed to thin the the stand. Path descriptions are analyzed, individually to determine the effect of operating rate changes, and in sets to determine the effect of geometric design parameter and operating strategy changes, on machine capabilities.

The remaining discussion will surround an example in which a set of design parameters are specified to meet functional requirements. In the example the objective is to specify a machine to cut and bunch trees in a stand which has been marked for thinning (*) to provide 60% residual basal area. The machine will be operated in straight paths which are spaced two boom lengths apart. All trees marked to be removed and all trees impeding machine operation will be cut. In the example

(*) A 0.405 Ha marked stand was provided by Clay Smith, USDA Forest Service NE Forest Experiment Station.

specification consists of choosing between a 3m x 4m and a 4m x 5.3m prime mover, and selecting a boom length between 3m and 11m. The intended operating strategy, the choice of prime-movers and the limits on boom length repesent functional requirements on the design.

A thinning feller-buncher must be suitable for removing selected trees while leaving the residual forest intact. Selectivity (S = number of trees removed selectively / total number of trees removed, Fridley and Jorgensen 1983) is a measure of the success in removing only the desired trees. The improvement in selectivity over row, or mechanical, thinning is plotted in figure 1. Both geometric modeling and simulation derived results are shown. Selectivity increases as the reach ratio (R = 2 x boom length / machine width) is increased but the rate of improvement decreases as R is increased.

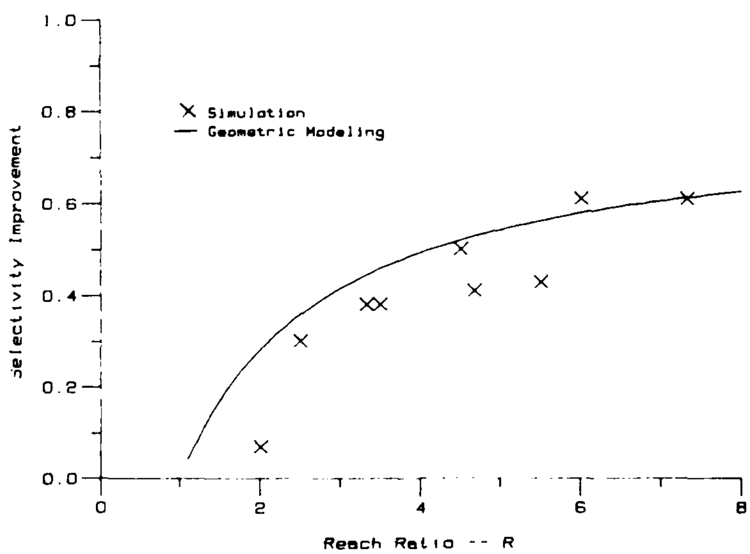

Figure 1. The effect of Reach Ratio on Thinning Selectivity.

The ratio of the actual number of trees in the residual stand to the prescribed residual number is shown in figure 2. Like selectivity, the capability for leaving the correct number of trees increases as R is increased but also with diminishing returns. Meeting the functional requirements of obtaining a given (silviculturally required) selectivity and leaving a prescribed number of trees specifies the necessary reach ratio. If, for example, selectivity 50% greater than mechanical thinning, or a thinned stand with at least 80% of the prescribed number of residual trees was desired, a reach ratio of at least 4 would be necessary. A 3m wide prime mover would then need a minimum boom length of 6m and a 4m wide machine would need at least an 8m long boom.

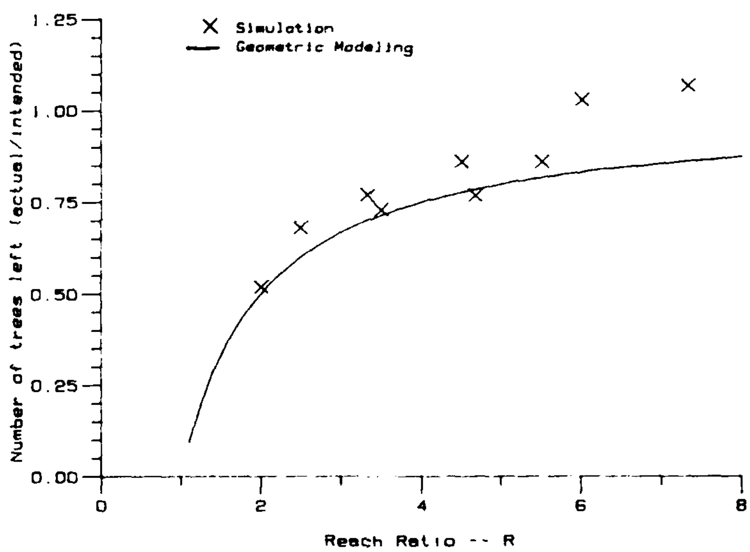

Figure 2. The effect of Reach Ratio on the number of trees in the residual stand.

Productivity of the feller-buncher is affected by both the geometric design and the operating rates associated with the various machine motions (Fridley, Garbini, Jorgensen and Peters 1984). Productivity of subsequent collection (yarding or skidding) of the felled trees is affected by the number of trees in each bunch. Bunch sizes, determined through simulation results, are shown in figure 3. The results displayed clearly demonstrate the increase in geometric reach area as the number of trees accumulated increases with the boom length squared.

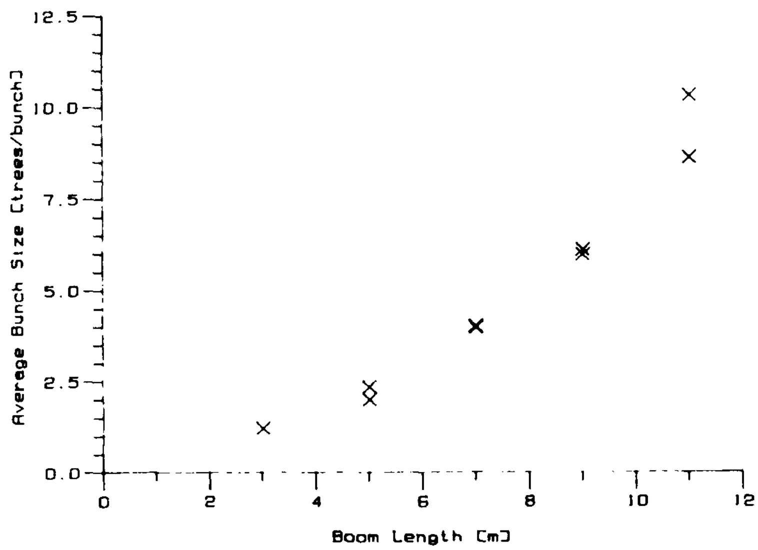

Figure 3. The effect of boom length on average bunch size.

Meeting a functional requirement of obtaining some minimum number of trees per bunch specifies a minimum acceptable boom length. For example, figure 3 indicates that meeting a functional requirement of two trees per (average) bunch takes a boom length of at least 5m, and obtaining an average bunch size of six trees takes a 9m long boom. A 5m boom corresponds to a reach ratio of R = 3.33 for a 3m wide prime-mover and R = 2.5 for a 4m wide prime-mover. A 9m boom corresponds to R = 6.0 and R = 4.5 for 3m and 4m wide prime-movers respectively.

Hardy (et.al., 1983) discussed the mechanical design of long booms for feller-bunchers. Normalized design parameters were developed based on lifting requirements at full boom length. It may not be appropriate, however, to design for lifting the heaviest tree at full boom reach. It may be more appropriate to design for the heaviest tree at the average reach distance or the average tree at full reach. Simulation generated boom reach data are given in figure 4. The maximum observed reach distance is nearly equal to the boom length but the mean reach distance is considerably less (approximately 2/3 of the full boom length for the longer booms).

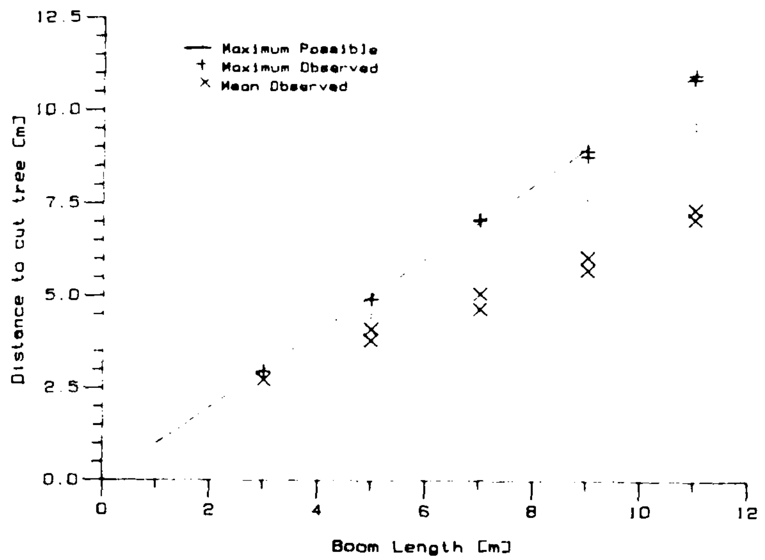

Figure 4. Maximum and average distance to trees cut.

Figure 5 shows the strength and cross section requirements (for bending) as a function of boom length for three lifting criteria. The lifting forces were chosen to illustrate average and heaviest tree and shear combinations. Selectivity may be compromised if too many trees are left uncut because of boom lift limitations, for example only 5% of the selected trees need to be left to raise the reach ratio requirement determined in the earlier example from 4 to 4.5, lengthening the minimum booms from 6 and 8m to 6.75 and 9 for the 3 and 4m wide prime movers respectively. Determining the best design strategy for lifting moment is currently under consideration.

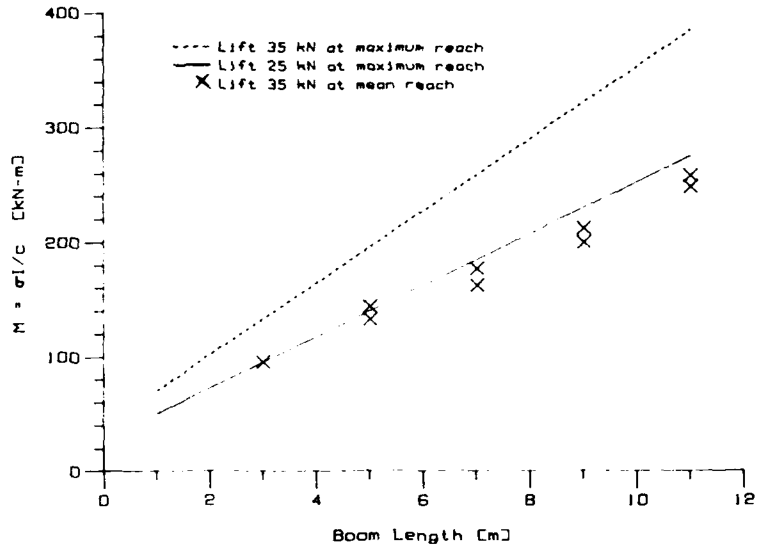

Figure 5. Feller-buncher boom structural design requirements.

CONCLUSIONS

Principles of systemetized Engineering design can be applied to the concept development of feller-bunchers for forest thinning. A hierarchical or level-of-detail based procedure will allow performance requirements to be addressed in terms of design parameters by developing Functional Requirement/Design Parameter relationships. The Design Parameters which are specified to meet primary performance requirements (e.g. selectivity) become requirements in the next level of design (e.g. boom lift).

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